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A Guide for Safety Inspection of Jumpform and Slipform Systems Used in Concrete Cooling Tower and Chimney Construction

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

September 1983

Sponsored by the
Occupational Safety and Health Administration
Department of Labor
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**A GUIDE FOR SAFETY INSPECTION OF
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USED IN CONCRETE COOLING TOWER
AND CHIMNEY CONSTRUCTION**

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S. G. Fattal

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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ABSTRACT

The increasing use of moving forms in the construction of many types of structures has prompted the need for special quality control measures in the field. Presently, slip forming and jump forming are the most widely utilized systems in the construction of cooling towers, chimneys, silos and nuclear reactor containment vessels.

This report is intended for use as a resource document by OSHA Compliance Officers for the safety inspection of jump form and slip form systems used in the construction of cooling towers and chimneys. The systems are described in terms of their components and operating procedures involved in the casting cycle of a typical lift. Special emphasis is given to the structural aspects of components which are most critical in the maintenance of overall structural integrity of the system during construction.

Keywords: chimneys; concrete strength; construction loads; construction safety; construction standards; cooling towers; jump forming; slip forming; structural safety.

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1. INTRODUCTION

1.1 GENERAL

The construction industry has developed increasingly more sophisticated methods of construction for many types of structures. Along with these developments have come various form and scaffold systems designed specifically for certain structure types. Many of these rely on partially completed sections of the structure for support; some are designed to interact with the structure in resisting applied loads.

Due to the complex nature of these systems, specific procedures and conditions must be used to safely operate the systems. The OSHA compliance officers conducting safety inspections must recognize the interrelationships of the various system components and should have a basic understanding of the system's operation when inspecting the facilities. With such knowledge, more meaningful inspections can be performed by the compliance officers.

1.2 OBJECTIVE AND SCOPE

The main purpose of this guide is to provide OSHA compliance officers with a basic working knowledge of jump forms and slip forms so that they can perform pertinent safety inspections. The intent is also to provide a grasp of the overall operational aspects of the construction system and to identify important items to safely operate the system.

The scope is limited to discussion of natural draft cooling towers and large chimneys, with some mention made of silos and containment vessels. At least two forming systems are discussed for each of the structures; variations in the design are noted.

1.3 ORGANIZATION OF THE REPORT

General discussions pertaining to jump forms and slip forms are presented in chapter 2, along with explanations of the general form types and their uses. In chapter 3, the construction of natural draft cooling towers is discussed, including different jump forming systems and critical safety items pertaining to each.

Slip forming methods and equipment for large chimneys are presented in chapter 4, with critical components noted for each. Other types of structures are mentioned in chapter 5. General discussions on construction safety for the form and structure types are summarized in chapter 6 along with conclusions and recommendations. Backup data are documented in appendices A through E to assist in the evaluation of the forming systems.

2. DESCRIPTION OF FORMING SYSTEMS

This chapter discusses general systems for concrete forming and typical methods of moving forms during the construction of natural draft cooling towers and chimneys. Similar methods are used on many other types of structures such as storage silos, containment vessels, building cores, and water reservoirs.

2.1 FORM TYPES

Forms can be categorized by the structural method used to resist the lateral force exerted by the hydrostatic pressure of fresh concrete (figure 2.1). Wood is most commonly used as the form sheathing, with other components typically being steel or aluminum.

2.1.1 Cantilevered

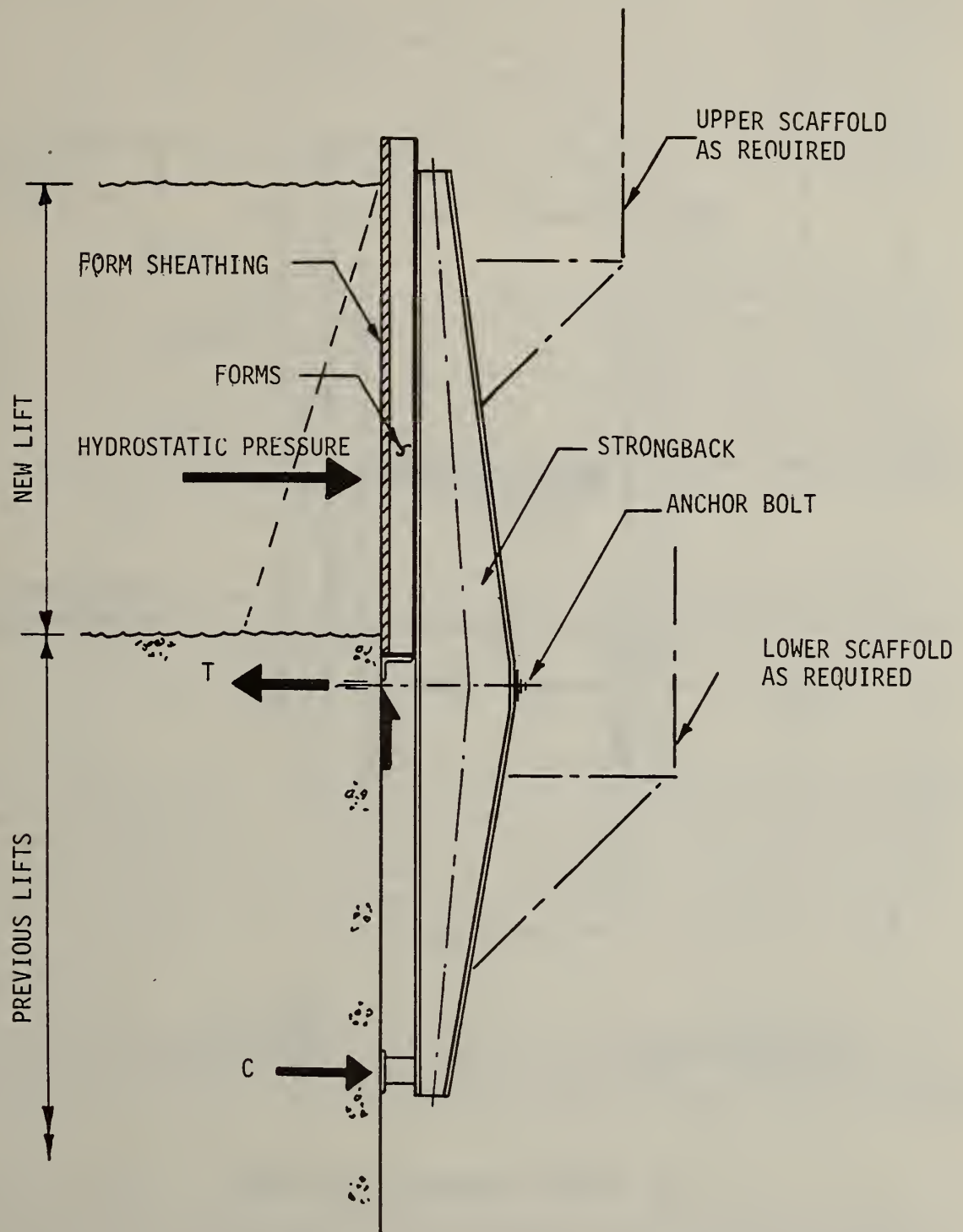
Cantilever forms resist lateral forces through cantilever action of structural elements; the elements transfer the applied loads to a support point, usually a heavy anchorage bolt in previous lifts.* Concrete gravity dams are the most common applications of purely cantilevered forms (figure 2.1a), but frequent use is made of the cantilever concept in most of the forming systems considered in these guidelines. Since the structures under consideration cannot be economically constructed using ground-supported systems, it is logical that the forming systems be supported by previous lifts of the partially completed structures. Vertically cantilevered members are anchored to the lifts and are used to support the complete forming and scaffold system and to resist moments and forces applied to the system.

As will be discussed in chapter 3, the sloping surfaces of natural draft cooling towers produce extraordinary overturning moments which must be resisted by the cantilevered elements. In such cases, the cantilevers not only must resist the eccentric weight of the forming system, but also the eccentric mass of fresh concrete in a lift being poured. The moments absorbed by the cantilevers result in high anchorage loadings on the lifts below. The anchor bolt loads and their distribution into the concrete are critical to the success of any cantilever system. Proper design, manufacture, and installation of the anchorage components is of utmost importance.

2.1.2 Internally Tied

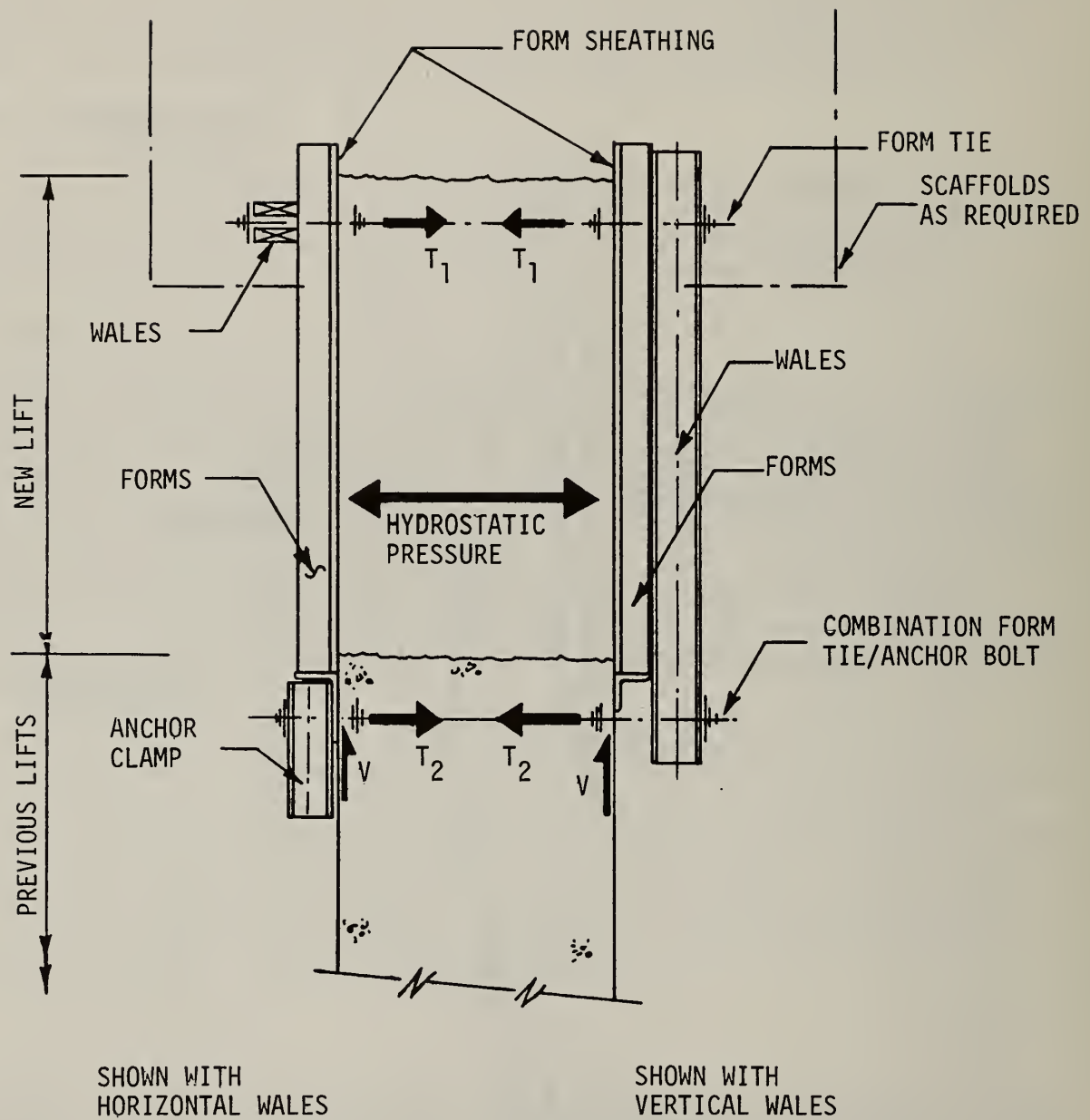
Due to the large lateral forces exerted by fresh concrete, cantilevers require substantial structural members and anchorages to restrain hydrostatic concrete pressure; therefore, most of the form systems use internal form ties to contain the pressures (figure 2.1b). This method generally results in the most economical forming system, since loads are resisted with localized tension members. Loads on the form ties are primarily dependent upon the height of pour, rate of concrete placement and setting, spacing of form ties, and location of ties. Form members spanning between ties are designed in accordance with deflection criteria in addition to strength requirements.

* A lift is a concrete section cast at the end of each moving and forming cycle.



(a) GENERAL CANTILEVERED FORM

Figure 2.1 Moving form types



(b) GENERAL INTERNALLY TIED FORMS

Figure 2.1 Moving form types (cont.)

Internal form ties are made of steel and are assembled in various manners. The one most often used in cooling tower construction consists of a central portion embedded in the concrete with each end threaded to receive an anchor bolt that is connected to the forms (figure 2.3). The construction is usually such that, after the concrete has hardened, an anchor bolt can be removed from either end, and the embedded central portion will retain the load-carrying capability of the other anchor bolt. Embedments with male threads are used with she-bolts; those having female threads, with he-bolts. Equal capacities can be designed for either type, but the thin wall sections and partially cured concrete may require special considerations.

2.1.3 Externally Braced

Wherever the use of internal form ties is uneconomical or impractical, it is common practice to resist the hydrostatic pressure with structural components external to the construction (figure 2.1c). Slip forms are often externally braced by a series of steel yokes at equal intervals which absorb lateral forces due to the fresh concrete acting on the interior and exterior forms (figure 2.4). Structures with concrete forms on one side, such as tunnels and underground shafts, make use of loadabsorbing frames acting as compression rings inside the formed section. Tension rings are commonly used to support forms for concrete columns and similar elements.

Externally braced form systems do not normally impart additional hydrostatic loads to the partially completed structure, since their basic design is to absorb the pressures. Concrete must be placed in a uniform pattern to prevent eccentric loadings on the system. The placement of concrete is a critical phase for externally braced systems, since stresses in certain of the structural components are at their highest levels.

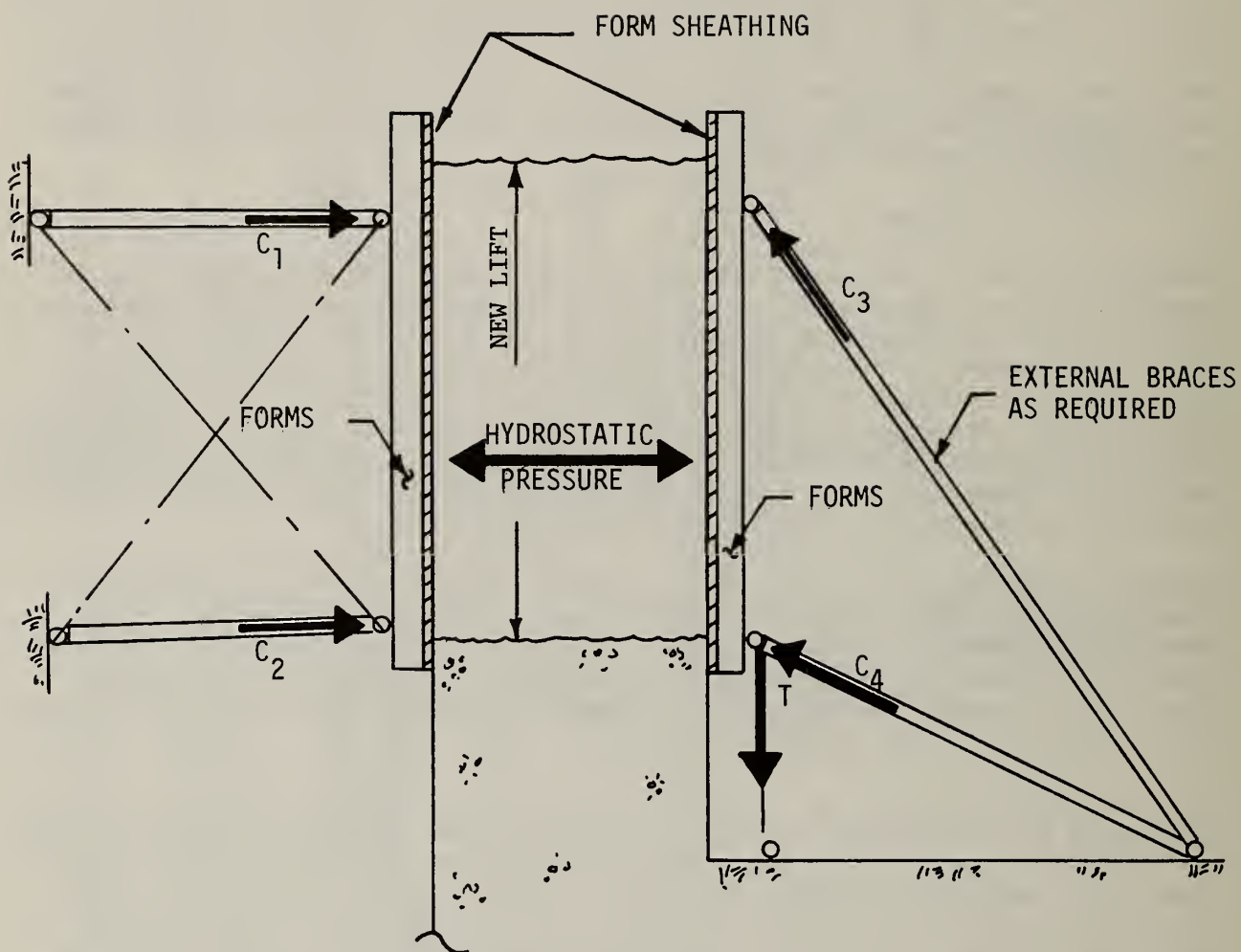
Forming systems may also be classified by the method used to reposition them at subsequent pour locations. Sometimes, forms must be dismantled, moved to a new position, and reassembled; such systems are not economically justified for structures considered in these guidelines. Those systems which remain intact and move semi-continuously while concrete is being poured are referred to as slip forms. Those which remain in position until the concrete has partially cured and are then moved intact to the next position are called jump forms.

2.2 JUMP FORMS

Jump forms are used on many types of structures; they provide the benefit of not requiring ground support while also serving as a stable work area suitable for adjusting cross-section, placing concrete, and performing other construction activities.

2.2.1 Application

Jump forms are used primarily on large structures and those requiring tighter control or changing geometry. Natural draft cooling towers make exclusive use of jump forms; three different systems are discussed in chapter 3. Other jump form systems are used to form nuclear containment vessels, underground shafts, building cores and other non-circular structures.



(c) GENERAL EXTERNALLY BRACED FORM

Figure 2.1 Moving form types (cont.)

Due to the intermittent movements made with jump forms, they lend themselves well to geometric changes and adjustments in alignment. Better control can be accomplished than with the faster slip forming methods. Likewise, concrete placement can be better controlled.

Many jump form systems rely on the previous concrete lifts for anchorage of cantilevered elements which, in turn, provide support for the entire forming and scaffold system. Therefore, concrete strength becomes very important with jump form systems; the movement of forms and scaffolds to successive lifts is also a critical phase.

2.2.2 Structural System Components

Jump form systems are composed of four sub-systems, as follows:

1. Structural Support: vertical and horizontal elements to tie the other subsystems, maintain overall shape of the structure being formed, and deliver loads to anchorages.
2. Forms: members containing surfaces against which concrete is placed to mold a face of the new structure and provide initial containment of hydrostatic pressure of concrete.
3. Scaffolds and Walkways: horizontal and vertical elements to provide access to all working areas of the form system.
4. Mechanical: elements used to adjust the shape or configuration of the form system and to move the entire system from one pour position to the next.

For economic reasons, manufacturers design the sub-systems with multiple functions; each one usually serves dual roles in the overall system. As an example, vertically cantilevered elements of the structural support sub-system usually contain mechanical items for moving the form system; they may also serve as part of the scaffolding or even as forms. Various names are given to these elements by the various manufacturers; they are commonly described as strongbacks (figure 2.2).

The strongbacks (also referred to as jump form beams, climbing frames, or raisers) deliver all un-absorbed loads to anchorages in previous lifts. The entire system is dependent upon the load-carrying capacity of the anchorages. Therefore, the importance of concrete strength in previous lifts cannot be overemphasized. Strongbacks can be tubular members, standard or customized structural shapes, or trussed sections; most often the shape used depends upon mechanical requirements and other functions required by the design.

Jump form systems discussed in this document make use of internal form ties (figure 2.3), which absorb the hydrostatic pressures exerted by the concrete.

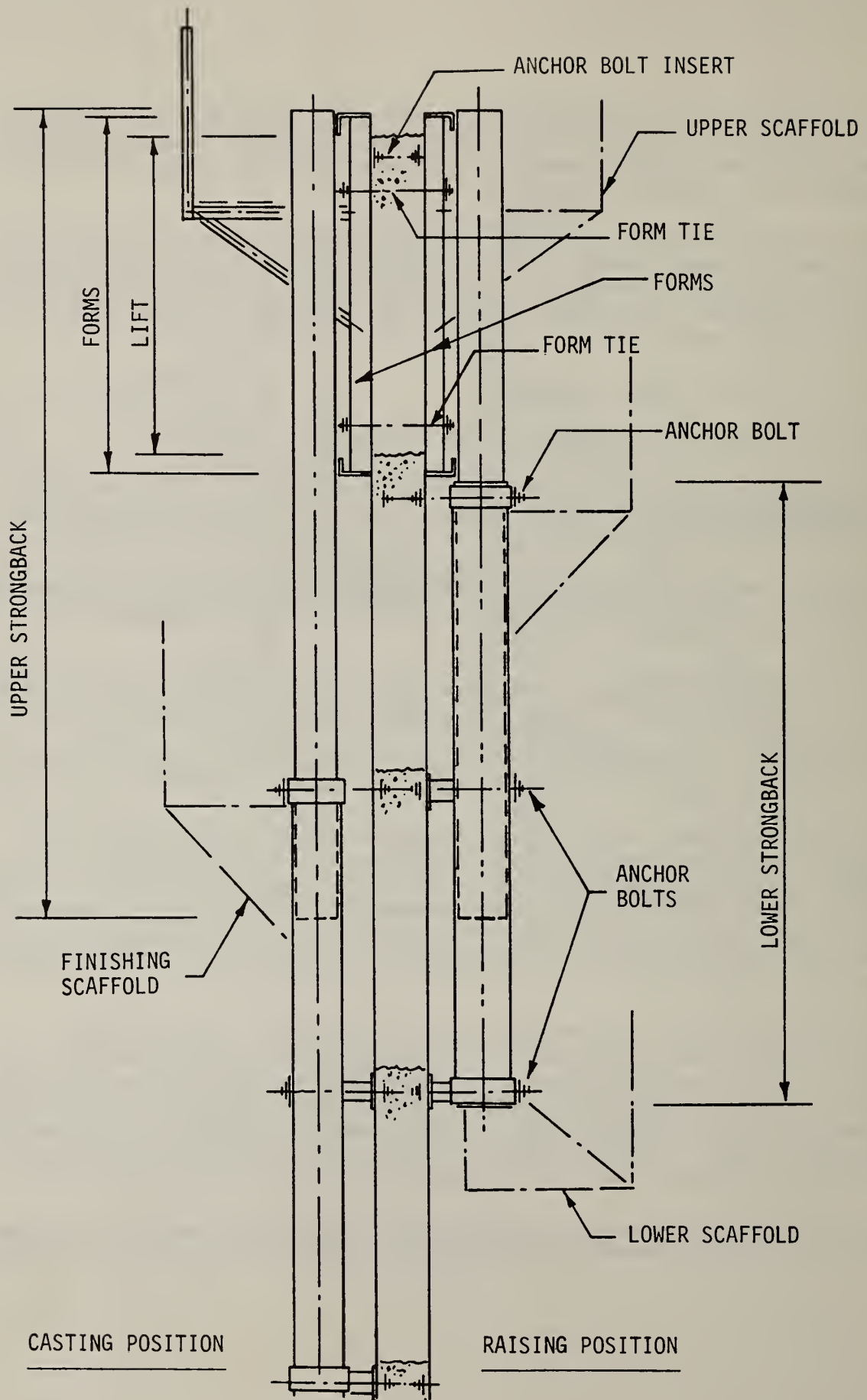


Figure 2.2 General jump form system

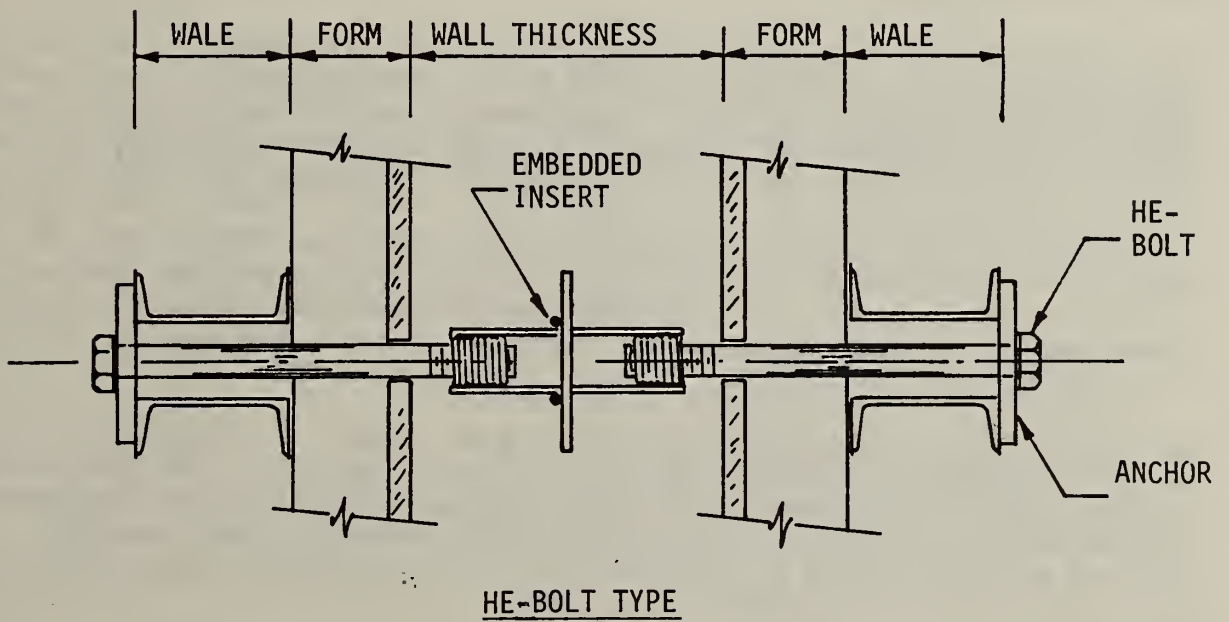
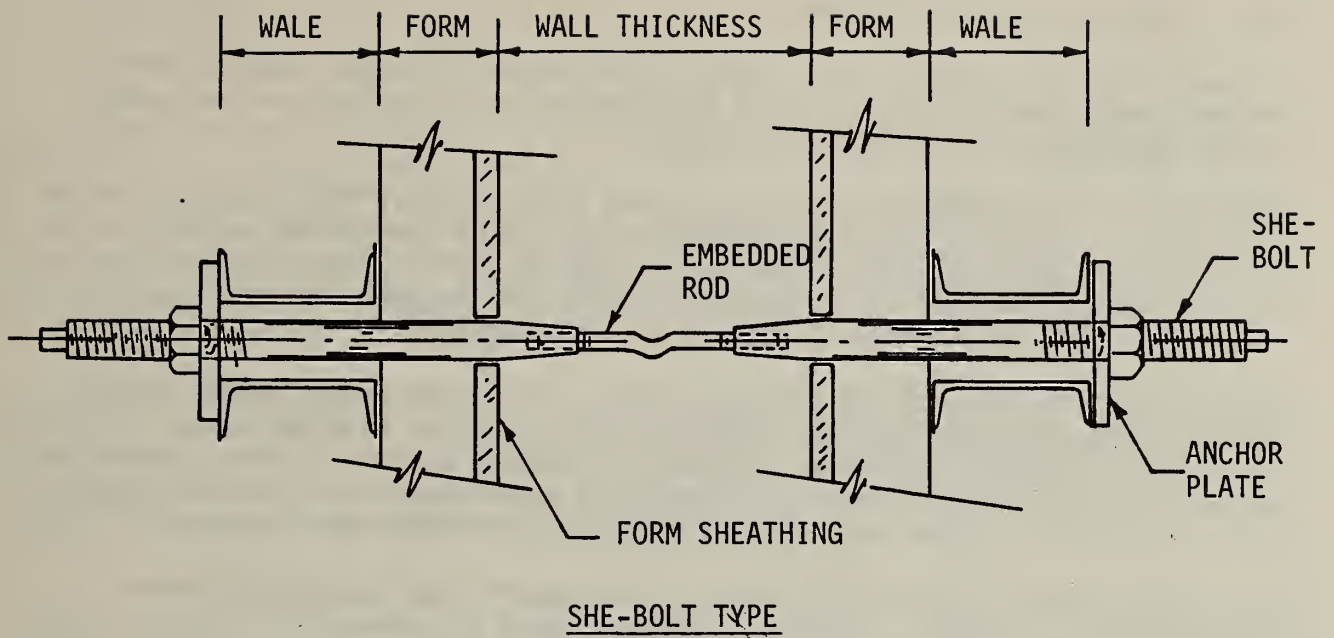


Figure 2.3 Reusable form ties

2.2.3 Methods of Raising Forms

The mechanical components used to move form systems from one pour position to the next vary considerably; factors influencing the selection are economics, safety, maintenance, and available power.

Hydraulic jacks are often used in both jump form and slip form systems. They may be used to provide direct movement through their telescopic action, or to operate some other mechanical function. Power to operate the hydraulic jacks may be electric, pneumatic, or internal combustion engine. Manual operation is too slow for the systems considered in this document.

Direct mechanical movement may be provided by ratchet actions, screw motion, winches, cable-climbing devices, chain hoists, or other similar items. One of the jump form systems discussed in chapter 3 uses a ratchet action powered by hydraulic jacks; another uses self-contained screw rods driven by portable air motors; the third system uses electric winches to effect the climbing.

Slip form systems often use hydraulic jacks which climb compression rods embedded in the concrete. Tension rods activated by hydraulic jacks are used to slip form vertical shafts and other types of structures.

Manual operation of chain falls and cable-climbing devices is generally limited to structures smaller than those considered in this report.

2.2.4 Problem Areas

The primary concern with jump form systems is their attachment to the partially cured structure. This attachment involves not only the anchor components, but the strength of concrete as well. Each form system produces different loading conditions and sequences of loading; a thorough engineering analysis is required with each system to determine the magnitude of loading and strength requirements.

It follows that the proper installation of all anchorage components is of equal importance. Concrete must be well consolidated around anchorage embedments during initial placement. Anchor bolts must be installed at the designated locations; the bolts must engage the embedment properly and must be uniformly tightened to specified values.

Due to the typical procedures involved in moving jump form systems, there can be critical loadings developed during the moves. There are specific sequences of events which can affect the loadings; personnel operating the form systems must be aware of the interrelationships of the various system components. Training and supervision of personnel must be established to insure the safe operation of the form systems at all times.

Some jump form systems cause blockage of normal accessways during the phases of moving forms from one position to another. Special precautions may be necessary during such times to provide alternate means of access or alternate routes for personnel.

2.3 SLIP FORMS

2.3.1 Application

Slip forms are used to build a variety of concrete structures. They are used exclusively on chimney construction and are usually found on the construction of silos and water reservoirs. They perform best on structures with a constant cross section and few penetrations, but newer methods allow slipping to be competitive with more conventional systems on structures having changing geometry and/or multiple penetrations. The major advantage is speed of construction, which usually results in monetary savings, with some sacrifice in tolerance.

As noted for jump forms, slip forms usually rely on previous concrete lifts for support, but generally do not produce concrete stresses as high as in the jump forms because overturning forces tend to be less. However, the slip forming systems apply loads to the concrete at an earlier age; therefore, the rate of strength gain of the concrete can become critical.

2.3.2 Structural System Components

Slip form systems are composed of the same sub-systems as jump forms (section 2.2.2), as follows:

1. structural support
2. forms
3. scaffolds and walkways
4. mechanical

Likewise, the slip form elements perform multiple functions. The most common elements of slip form systems are the yokes (steel frames with inverted-U shape, figure 2.4). They serve to contain the hydrostatic concrete pressure, deliver loads to climbing rods, support scaffolds and work decks, and serve as a portion of the mechanical slipping system (see figure 2.4). For containment of hydrostatic concrete pressures, slip forms are classified as externally braced, since integral form ties cannot be utilized. The yokes serve as the main containment members with forms spanning horizontally between yokes.

Slip forms move upward semi-continuously to prevent adherence of the fresh concrete to the forms. The rate of movement is dependent upon the structure size, rate of concrete delivery, and concrete characteristics. Typical slip forming results in a construction rate of 6 to 12 in/hr (150 to 300 mm/hr). Many structures, such as chimneys discussed in chapter 4, operate on a 24-hour basis. Other structures are constructed on a day shift basis, with a skeleton crew at night.

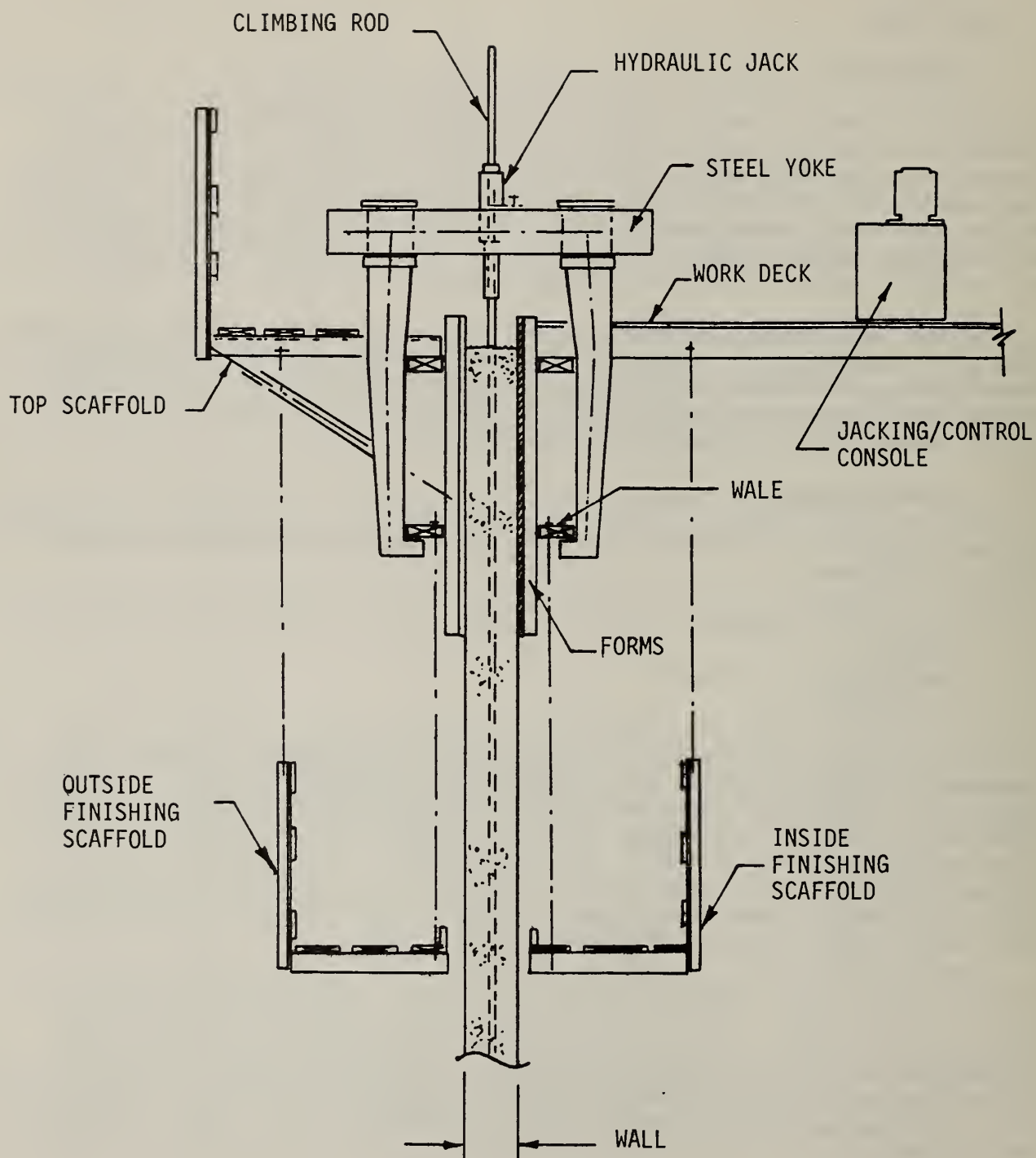


Figure 2.4 General slip form system

2.3.3 Methods of Raising Forms

Slip forms can be classified into two general categories: (a) those suspended from overhead structures and (b) those supported directly by materials embedded in the concrete being placed.

Underground shafts are slipped with forms suspended on multiple rods anchored at ground level on top of the shaft: synchronized hydraulic jacks raise the forms by simultaneously lifting all of the rods (figure 2.5). Small diameter above ground structures may be slipped using a central mast or tower and spider frame from which the forms are suspended (figure 2.6). On such systems, the forms may be raised by manually operated chain falls or cable-climbing devices.

In general, the most common slip form systems are supported by vertical rods centrally embedded in the concrete walls. The rods are located at each yoke and hydraulic jacks on the yokes are used to climb the rods. Structurally, the rods act as slender columns anchored at the base and cantilevering upward to the attachment point of the hydraulic jack, where the vertical loads of the forming system are applied. Therefore, the size and unbraced length of the rods is a critical element in the design of slip forms. Pipes are often placed concentrically around the rods to provide additional bracing. The pipes remain attached to the yokes and travel upward with the forms; the rods remain stationary in the concrete and become part of the structure reinforcement. Additional sections of rod are spliced onto the top of the embedded rods as the slipping process continues.

2.3.4 Problem Areas

Due to the continuous nature of work for slip forming, the in-place strength of concrete is of primary importance. The contact time of the forms with the freshly placed concrete is about 3-4 hours, meaning that the concrete must be self-supporting and be able to sustain additional loads at a very early age. Consistent quality is a necessity for safe and successful slip-forming. Continual inspections must be made during the slipping process to insure that the concrete emerging from the base of the forms meets specified conditions. Various in-place test methods are available to estimate the strength of the newly exposed concrete and to determine the elevation of set concrete within the forms.

As stated earlier, the climbing rods are very important to the safety of the slip forms. Due to their slender nature, the rods must be designed for anticipated maximum unbraced lengths. Such design lengths should not be exceeded without an analysis of the possible effects. Since the unbraced length extends from the top of set concrete to the point of fixity at the hydraulic jack, large diameter rods may be required for extraordinary lengths. Auxiliary bracing is usually provided in order to reduce the required sizes; for such designs, installation of design bracing is most important.

Geometric control of slip forms is more difficult than that of jump form systems due to the continual movement of the system. In addition to changes to the cross-section, operation of the slip forms must correct for alignment of the system and for penetrations (i.e.: window openings) through the concrete.

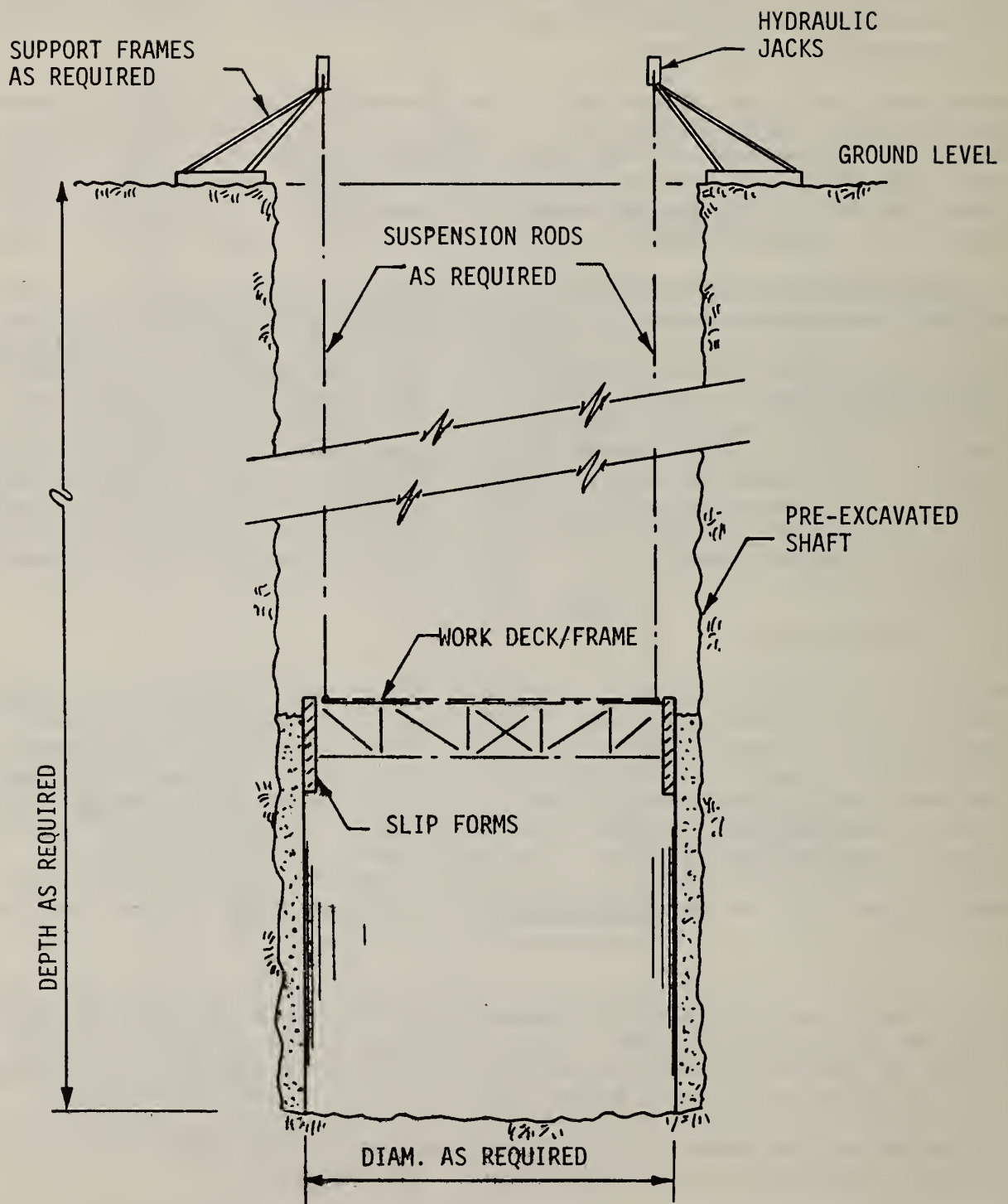


Figure 2.5 Slip form for underground shaft

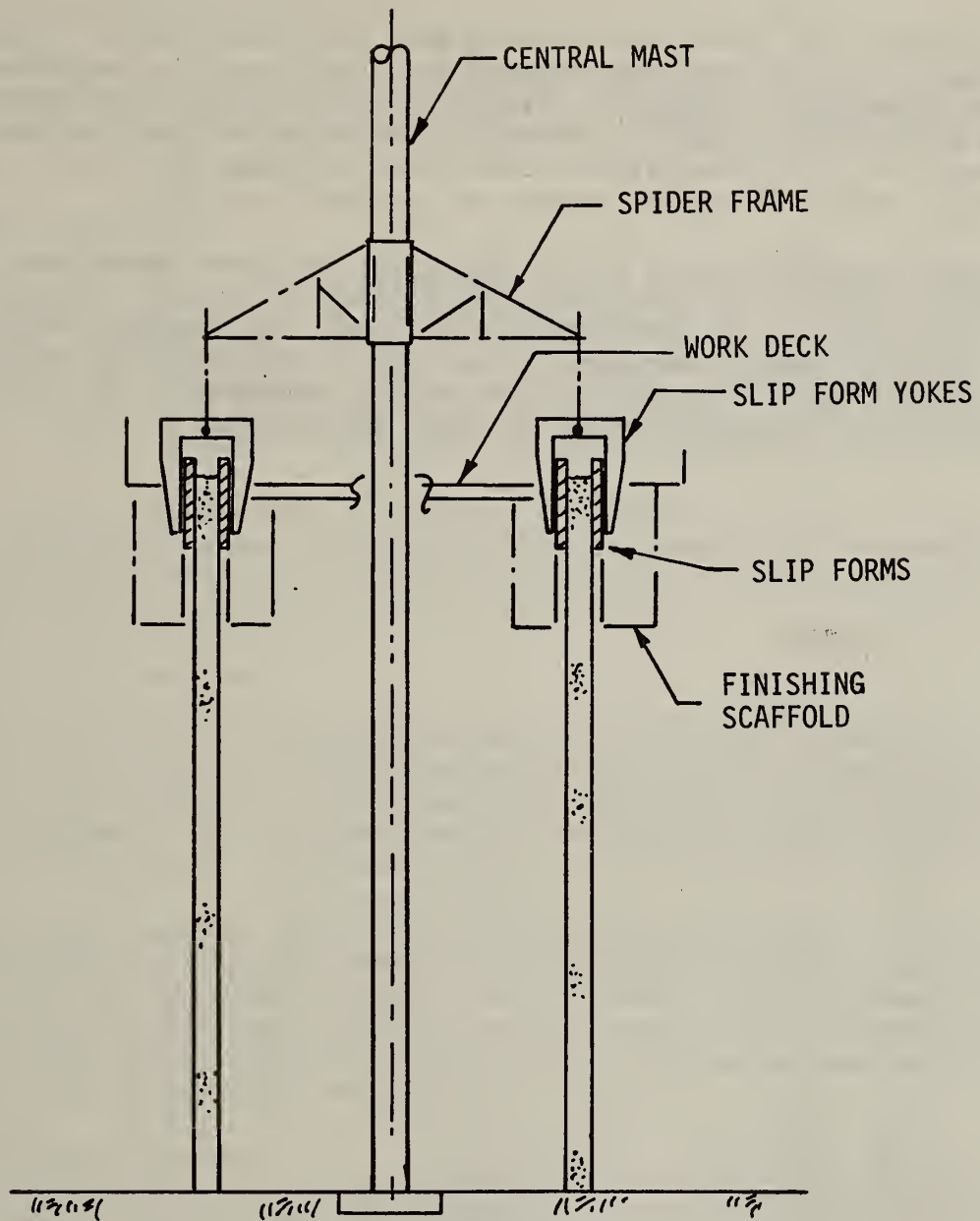


Figure 2.6 Slip forming with central mast

Weather changes can affect slip forming more than jump forming. Sudden temperature drops can halt the slipping operation since the hardening rate of concrete is adversely affected. Similarly, rain can stop slip forming, unless special provisions are made to prevent contamination of the concrete. Night operations also introduce difficulties to the slipping operations, such as maintaining proper alignment, because of reduced visibility.

The chance of operator error is increased with slip form operations. Most systems employ hoists and elevators for delivery of materials and personnel from ground level to the form system work decks. The changing height of the system requires special awareness by the hoist operators. The overall safety of suspended slip form systems is particularly dependent on the structural integrity of the suspension rolls and their attachments.

3. COOLING TOWER CONSTRUCTION

This chapter deals with the safety aspects of the forming systems most commonly utilized in the construction of large reinforced concrete natural draft cooling towers.

3.1 GENERAL DESCRIPTION

The towers consist of a concrete shell formed in a hyperbolic curve shaped with variable diameter, positioned on columns above ground level (figure 3.1). The shell usually has a thickness of 7 or 8 in (178 or 203 mm) with sections at the base and at the top thickened to about 36 in (910 mm). Diameter at the base of the shell is usually 200 to 400 ft (60 to 120 m); at the throat, 125 to 250 ft (38 to 76 m). Overall height is in the range of 300 to 600 ft (90 to 180 m).

The thin shell and massive size of cooling towers present unique construction problems. Different systems have been developed by industry to accomplish their construction [1].* Variations in the systems require different procedures for their inspection and operation.

3.1.1 Uses of Cooling Towers

The towers considered in this guide are used in the process of reducing the temperature of water used to cool steam generators at power plants, both fossil fueled and nuclear powered. The hot water is distributed at the base of the tower via a system of spray nozzles, and air is drawn into the tower by the thermal rising effects of the heated water.

Efficiency of the tower is influenced by its shape and finish, requiring that the forming system be fully adjustable with provisions for finishing of the shell surface. The adjustability and other provisions found in system fabricator's or form designer's specifications tend to complicate the inspection and operation of the system, requiring more training of personnel and additional safety checks during installation and use.

3.1.2 Construction Methods

The large size of cooling towers generally dictates that the shell of the tower be cast in place; other portions are often precast.

One common procedure is to erect precast columns on poured footings, connect the tops of the columns with precast lintel beam sections, and pour a section of the shell in place to integrate the precast components. A system of jump forms is then installed on the integrated portion to begin forming the shell in 5 to 6 ft (1.5 to 1.8 m) lifts.

Another procedure is to cast the columns and lintel beams in place with a monolithic pour, followed by installation of the jump forms for the tower shell.

* Numbers in brackets identify references listed at the end of the report.

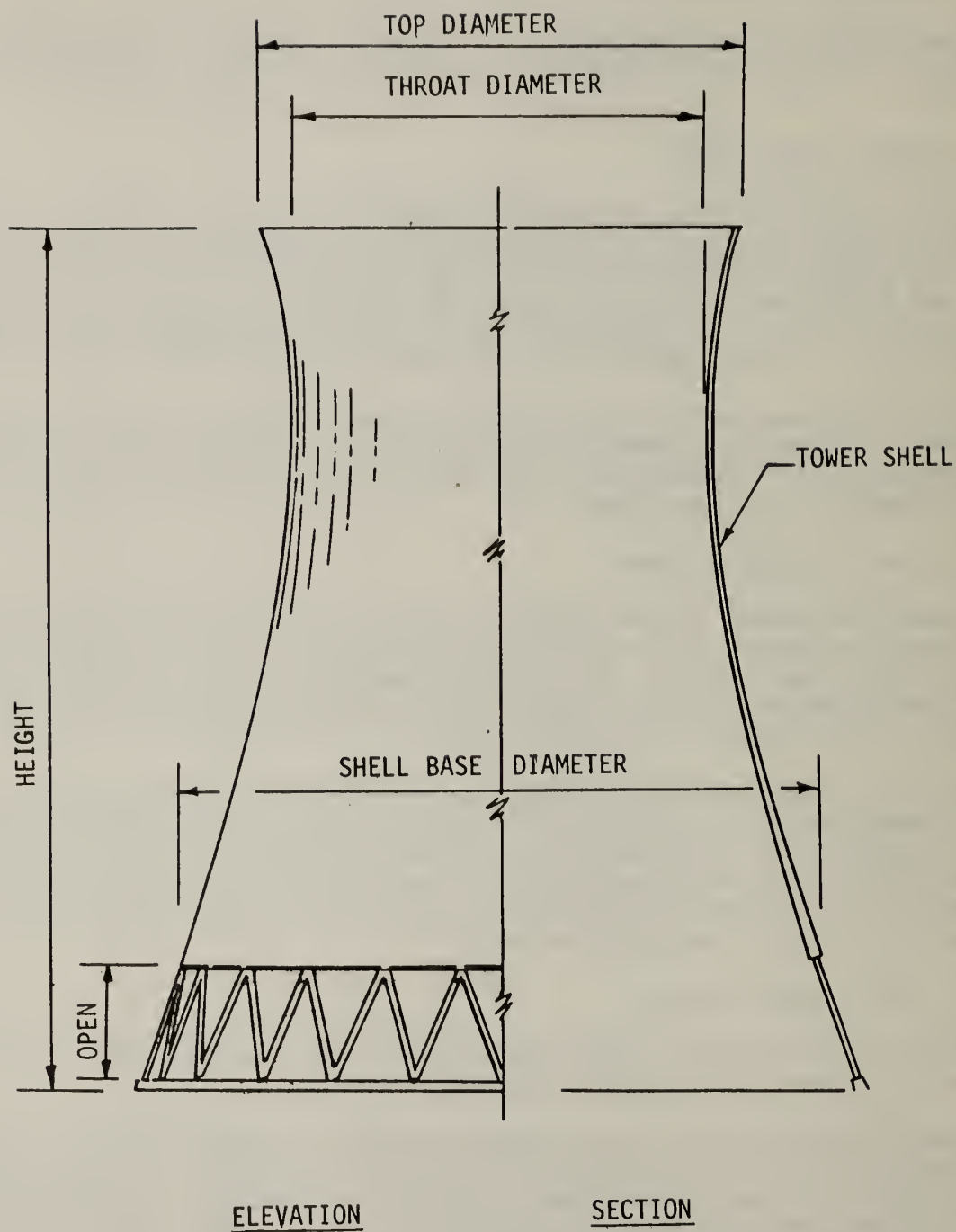


Figure 3.1 Natural draft cooling tower

All shell form systems rely on the completed shell portion for their support, making the attachment of the forms to the shell and the strength of the shell of utmost importance. The varying inclination and curvature of the shell make its analysis difficult [2], and it is further complicated by the different concrete strengths in succeeding lifts.

The general procedure for shell construction follows a one-lift-per-day cycle as follows:

1. Inside and outside strongbacks are released, raised to the next higher position, and reanchored (figure 3.2a).
2. Forms are stripped on one side of the wall, raised to the next lift, and positioned (figure 3.2b).
3. Reinforcing steel is placed for the next lift. This may also be done before or after forms are moved (figure 3.2c).
4. Forms for the other side of the wall are stripped, raised to the next lift, and positioned. They may also be moved simultaneously with the first set of forms (figure 3.2d).
5. Form ties and embedded anchors are installed, and form filler pieces are placed.
6. Concrete is placed.

The operations on some systems [3, 4] can be performed in a progressive manner with staggered work shifts and by distributing the workmen circumferentially. Concrete placement may begin at one location prior to completion of preparation activities at other locations.

3.2. SELF-RAISING UNITIZED JUMP FORM SYSTEM

There are certain forming systems which utilize discrete units of forms to construct the tower shell (figure 3.2e) [3, 4]. These are essentially self-contained independent units for forming a vertical section of the shell in lifts. Multiple numbers of the units make up a complete ring of form to cast the full diameter of the shell in a monolithic pour.

3.2.1 System Description

Two systems which perform the same functions but differ substantially in the materials used, overall unit size, and mechanism of movement are described below. System A is used to pour daily lifts of 6 ft (1.8 m); system B, 5 ft (1.5 m).

System A

This system makes use of forming units composed of reusable steel form panels bolted together into a set approximately 41 ft (12 m) long by 7 ft (2 m) high

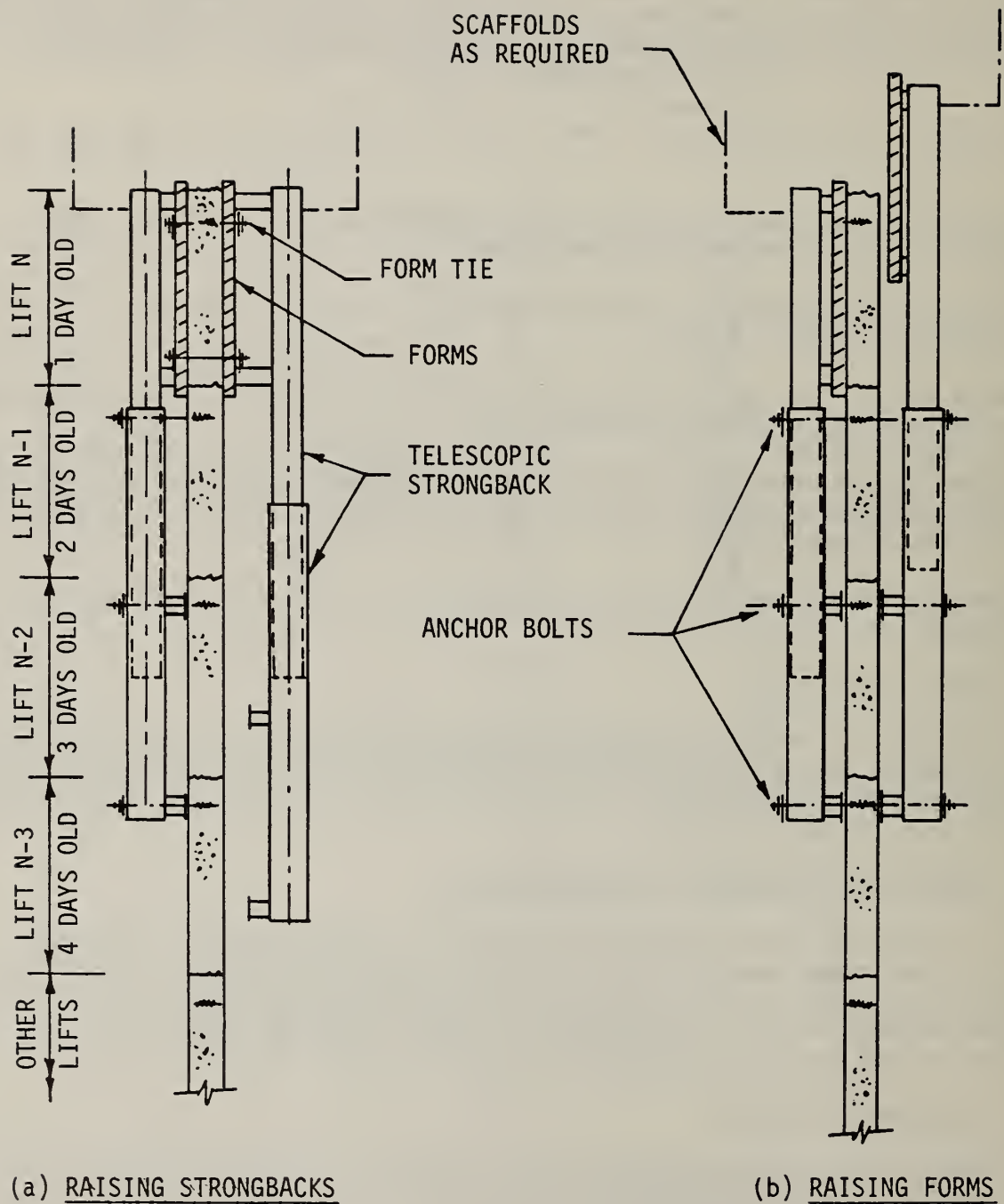
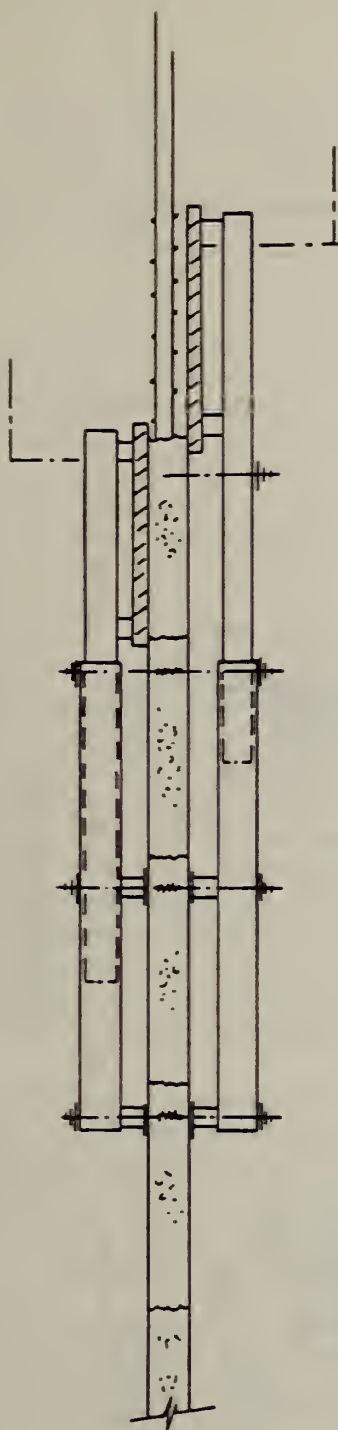
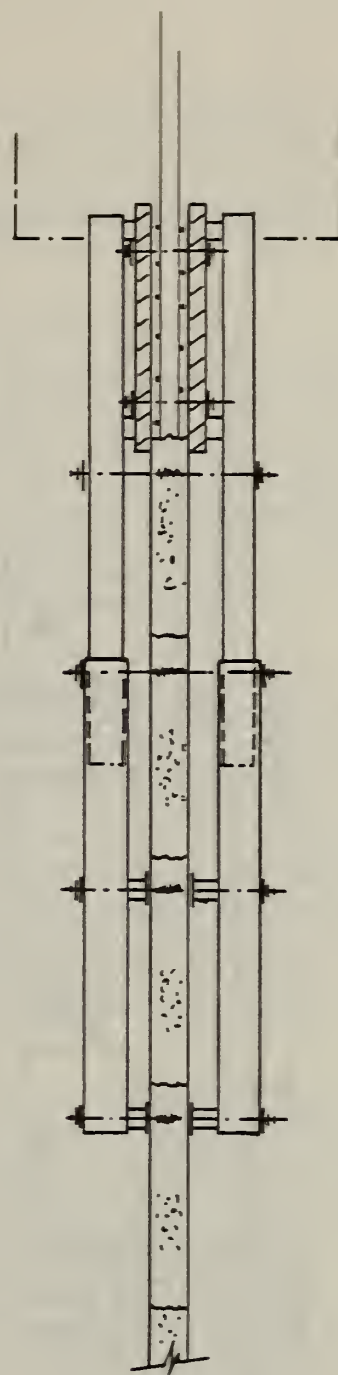


Figure 3.2 Unitized jump form system A

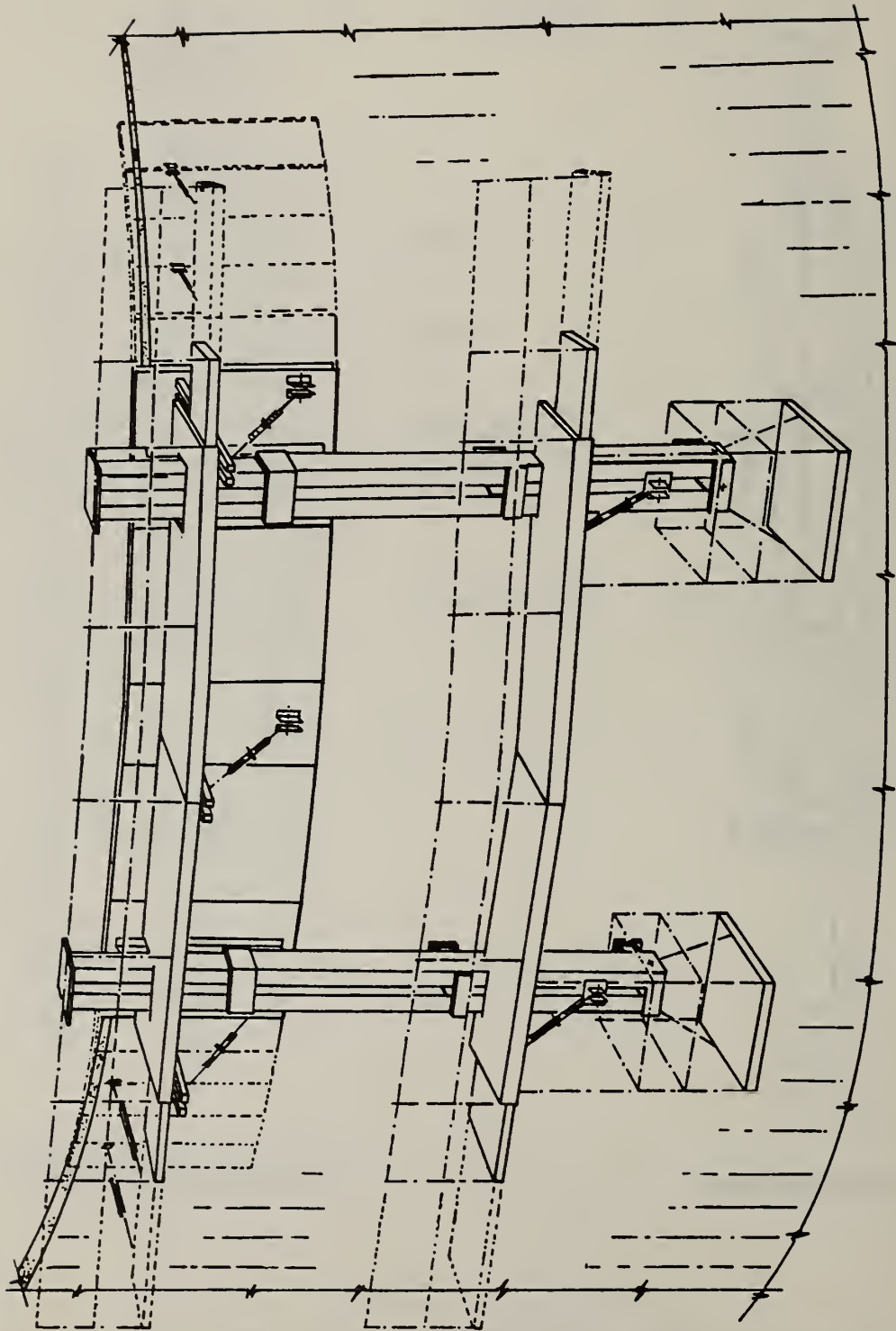


(c) PLACING REBAR



(d) CASTING POSITION

Figure 3.2 Unitized jump form system A (cont.)



(e) GENERAL VIEW

Figure 3.2 Unitized jump form system A (cont.)

(figure 3.2e). The length is adjusted to meet the changing circumference by removal of form panels on each end. A telescopic horizontal truss serves as a backbone for the set of forms to match the varying curvature of the shell. Adjustments are made with screw threads connecting the truss to the individual form panels. The truss also serves as the support framing for the upper scaffold.

A pair of telescopic vertical strongbacks supports the set of forms and truss during the cycle of moving to the next higher lift. These strongbacks are connected together by another horizontal truss which also serves as an intermediate scaffold. An internal screw mechanism in the strongbacks controls the telescoping and is used to raise the forms one full lift in a single cycle. Through a reverse action, the screw also raises the strongbacks to the next support position; appropriately, these strongbacks are generally referred to as raisers. A small work platform is located at the base of each raiser for access to the lowermost anchor bolt.

The combination of raiser, forms, trusses, and related items is called a "gang". Many gangs placed adjacent to one another make up an internal ring of forms for the shell; similar gangs in matching numbers make up an external ring of forms for the outside shell surface. The gangs are placed such that the inside and outside raisers are exactly opposite one another; with anchor bolts, the opposing raisers act in unison to resist overturning moments of the shell. Each pair of gangs is independent of other gangs and concrete may be placed in the forms for any gang once geometry adjustments are made and form ties are in place, regardless of the status of other gangs. This feature lends itself well to the staggered work shift and progressive procedures used in the cycle. Plywood filler boards span the gaps between form panels in adjacent gangs to provide a continuous forming surface.

A description of the daily moving cycle is given below to allow a better understanding of the operation of the system and the imposed loading conditions. Beginning with the previous day's lift of concrete poured and cured to a prescribed strength (which may vary according to shell design and geometry), all form ties in place, and all anchor bolts in place, the following sequence takes place at each gang (see figure 3.3):

1. Without removing form ties, the anchor bolts are removed for the raisers on the inside gang. This leaves the pair of raisers, the intermediate truss/walkway, and the lowermost work platform suspended from the forms and upper truss/walkways through the self-locking action of the internal screw mechanism in the raisers (figures 3.2a and 3.3a). Self-locking dogs in the raisers prevent the raisers from sliding apart in the event the screw mechanism were to fail. The shear forces on the raisers and walkway are primarily handled by the action of the forms and form ties; overturning moments are resisted by the previous day's lift of concrete and by the pair of external raisers still anchored to older lifts.
2. The screw mechanism is activated on each of the suspended raisers by a portable pneumatic-drive motor placed on the respective raisers. The mechanism lifts the raisers and connected walkways 6 ft (1.8 m) to the next

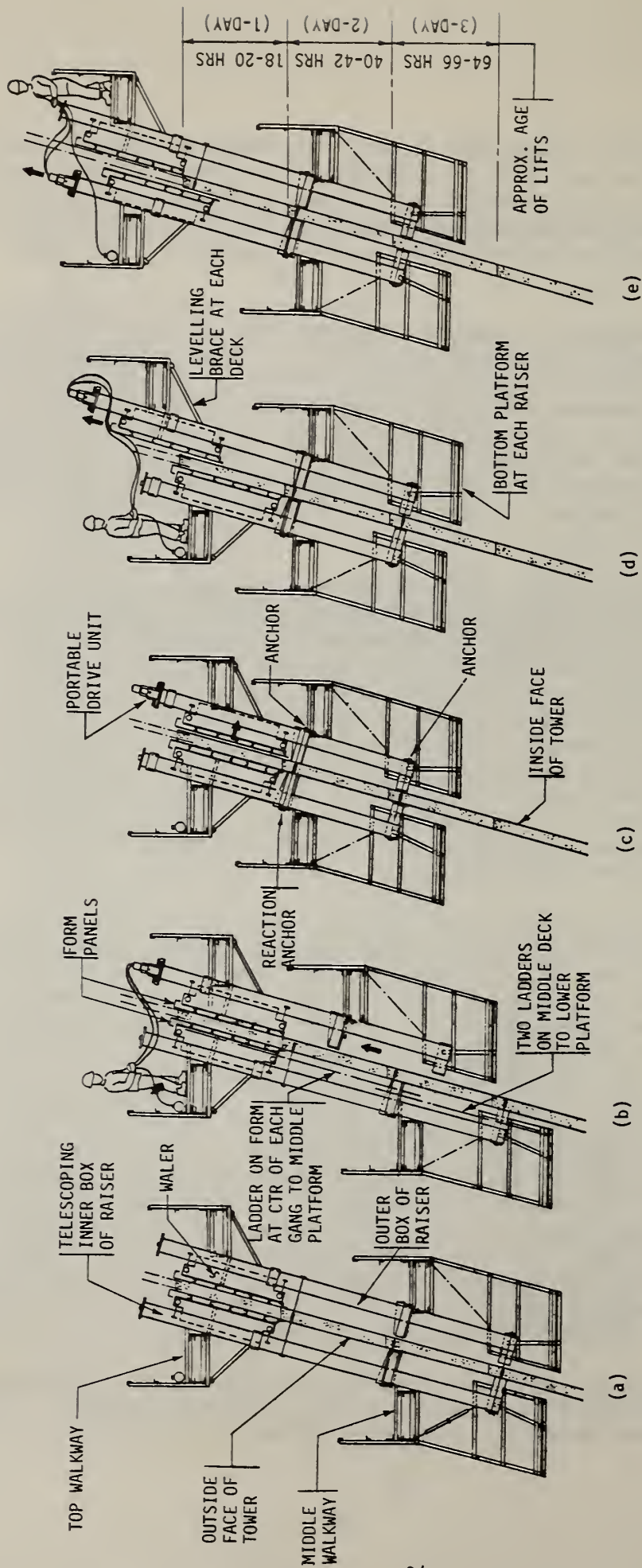


Figure 3.3 Jump form moving sequence of unitized system A

position, where the raisers are each anchored at two levels (2-day and 3-day old concrete).

3. Again without removing form ties, anchor bolts are removed on the outside pair of raisers, leaving the raisers suspended from the forms as before. The raisers and connecting scaffolds are then raised to the next position and re-anchored at the same two levels as the inside raisers.
4. With both sets of raisers up and anchored, the form ties are released for the inside set of forms and they are stripped from the concrete with screw threads connected to the raisers (figure 3.3b). This leaves the forms and upper walkway supported by the raisers through cantilever action. Shear forces are taken at the lower anchor (in 3-day old concrete); overturning is taken by tension in the upper anchor (in 2-day old concrete).
5. The screw mechanism is then used to extend the telescopic raisers and lift the forms and upper scaffold to the next pour position (figures 3.2b and 3.3c). The self-locking dogs serve to prevent the upper section from sliding down in the event the screw mechanism were to fail. Leveling of the set of forms is accomplished by adjusting the raiser screw mechanism. Curvature adjustments are made with the screw threads connecting the form panels and upper walkway truss. The bottom of the forms is brought into contact with the top of the previous day's lift, anchor clamps are installed to hold the forms tightly against the shell, and the slope of the panels is set. Embedded anchors from the previous day's lift become exposed when the forms are raised, and another anchor bolt is installed in the day-old concrete to add stiffness to the extended raisers. This final anchor bolt provides the third level of attachment of the raisers to the shell and provides additional overturning moment resistance (figure 3.2c).
6. After reinforcing steel is placed, the outside forms are released, stripped, raised, and re-set at the next pour position in the same manner as the inside forms (figure 3.3d).
7. Installation of form ties connecting the inside forms to the outside forms is made and the forms are ready to receive fresh concrete. Hydrostatic pressure of the concrete is resisted by the form ties and anchor clamps. Overturning moments and other lateral forces are resisted by cantilever-action of the two pairs of raisers and their attachment to the lifts below (figure 3.2d and 3.3e).

As can be seen from the preceding description, the sequence of events is critical; it is simplified by training small work crews with specific tasks and with staggered work shifts. Each crew performs the same function on each gang of forms and progresses circumferentially around the complete ring of forms. By agreement between the contractor and labor representative, on some projects the workers can be released for the day when their tasks are completed in the proper manner, but they receive a full day's wages. The incentive thus created benefits the job progress by promoting early completion of each day's activities.

Dependent on the size of the cooling tower, there will be 15 to 25 workers involved in the moving process for the typical cycle. Using the specialty crew concept, they will be located at different scaffold levels on the system and at different locations around the circumference. Progression of the operations is in clockwise fashion, with each crew completing its work on each gang prior to the next crew beginning. Design of the raising mechanisms is such that no worker is required on the form gang during raising of strongbacks or forms.

System B

This system uses wood forms attached to a reusable steel framework to accomplish the forming of the tower shell. Like system A, it utilized anchors set in previous lifts as a means of support during the construction cycle. However, the system differs in most other respects. Each gang has an overall length of about 18 ft (5.5 m) and a height less than 6 ft (1.8 m).

The plywood face of the forms is attached to a wooden frame shaped to an average radius of curvature to approximate the minimum and maximum radii to be formed on a particular tower. Curvature adjustments are not made during the tower construction, since the arc sections of each form closely match desired curvature. A steel frame containing three levels of scaffold supports the wooden forms and is connected to a "jacking frame" containing mechanical parts used to simultaneously raise the forms and all three walkways to successive lifts.

The jacking frame consists of a pair of vertical steel members about 6 ft (1.8 m) apart and connected together by bracing [4, 5]. Each of the vertical members hooks onto a bracket anchored to the tower shell, which supports the unit of forms and scaffold. The steel framework holding the forms and walkways is attached to the jacking frame in a telescopic manner and is also equipped to hook onto the same anchor bracket. Operation of the jacking frame is accomplished with an electric cog winch or hydraulic cylinder.

The following description of the daily construction cycle should offer a better comprehension of the system and its loading conditions. Beginning with the previous day's lift poured and cured to a predetermined strength, with all form ties and anchor bolts in place, the following daily cycle is used (see figures 3.4 and 3.5):

1. Starting with forms in place against previous day's pour (figure 3.5a), form ties are removed for both inside and outside forms, and the forms are stripped with a mechanical lever system built into the supporting steel frame (figure 3.5b). This leaves the gangs suspended from anchor brackets at two levels (in 3-day and 4-day old concrete); no support assistance is given to the inside forms by the outside forms, and vice versa. With the forms stripped, the lift from the previous day supports only itself.
2. On the inside forms, the jacking mechanism is activated and the jacking frames are released from the lower bracket and raised to the next bracket position (figure 3.5c), where the jacking frame is attached (figure 3.5d). During the movement of the jacking frame, the whole gang is suspended from the anchor brackets in 3-day concrete.

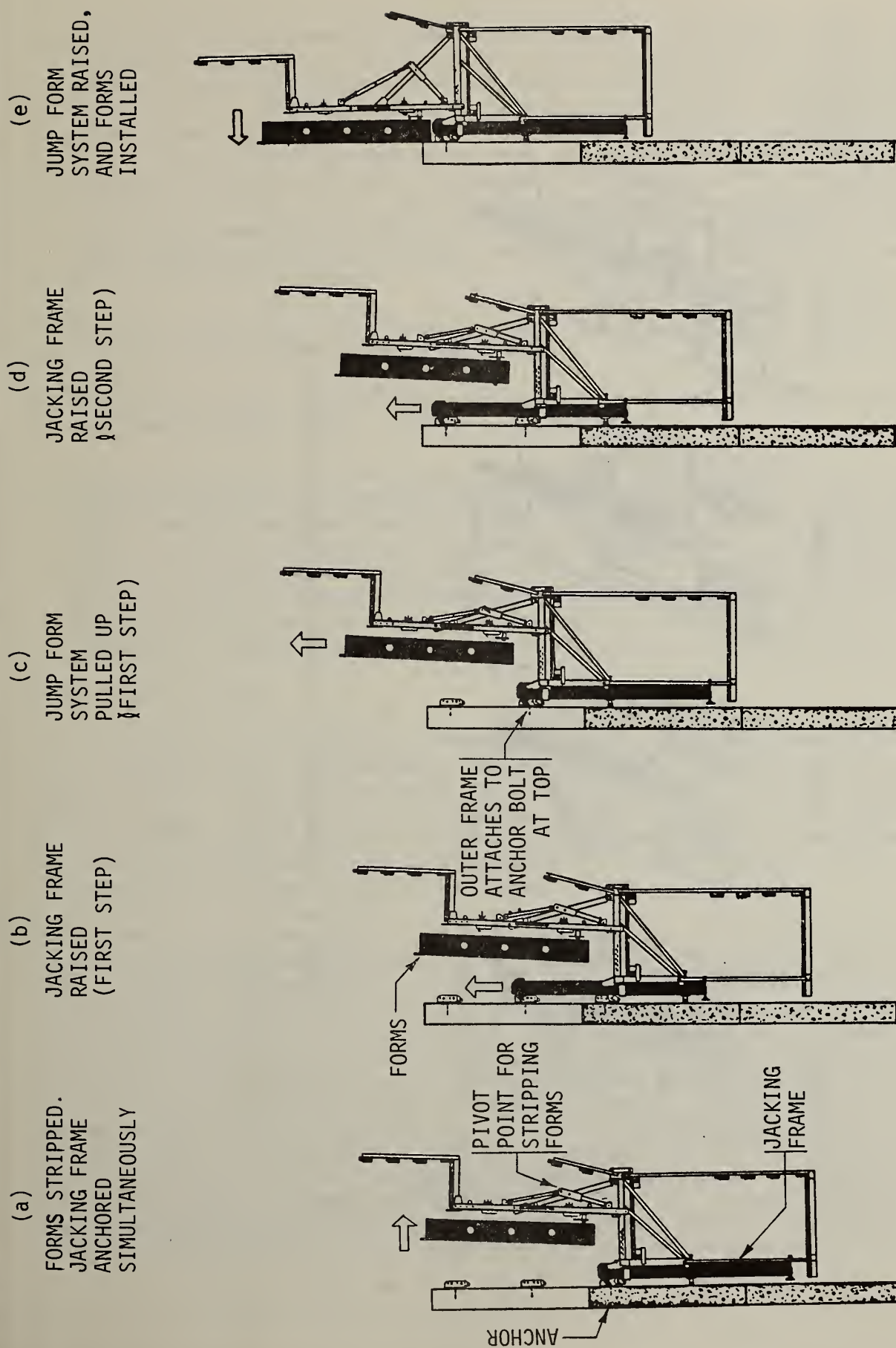


Figure 3.4 Stepwise jacking of forms for unitized system B

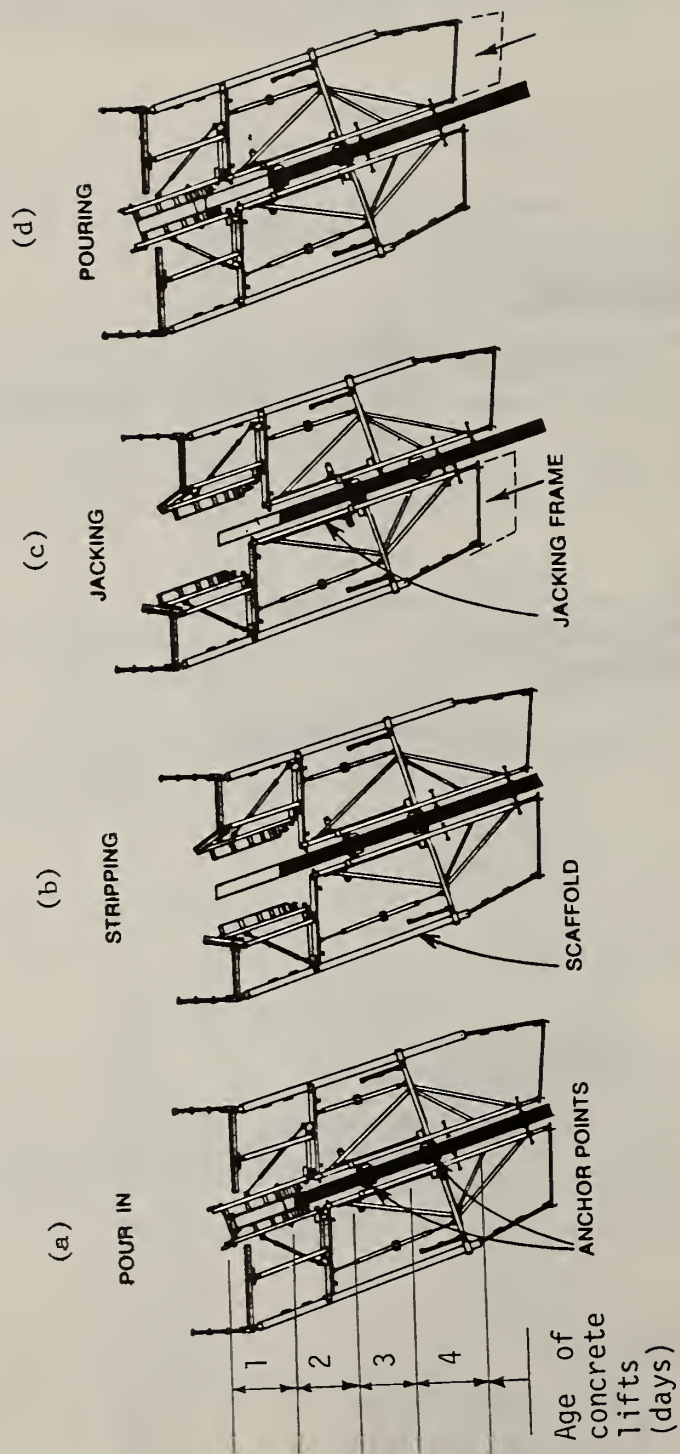


Figure 3.5 Moving cycle of unitized jump form system B

3. With the jacking frame attached to the bracket at the 3-day level, the inside steel frame with walkways is released and raised to the next pour position in a series of steps along the circumference of the tower (figure 3.4). Another bracket is installed at the 2-day level and the steel frame with walkways is attached to it. During the raising of the frame and scaffolds, the entire gang is still suspended from the anchor brackets at the 3-day level, through the connections to the jacking frame. The anchor brackets carry all shear and tensile forces created by the overturning moments. An adjustable screw at the base of the steel frame takes compression forces from the overturning moments and adjusts the slope of the steel frames.
4. Like the inside gang, the jacking frames for the outside gang are released, raised, and attached at the 3-day level.
5. The outside steel frame is released and raised to the next position like the inside forms (figure 3.5d).
6. After reinforcing steel is placed, the bottom of both the inside and outside forms are set against the top of the previous day's lift, thru-the-wall ties are installed, and the forms are ready to receive fresh concrete after geometry adjustments are completed (figure 3.5d). Hydrostatic pressure of the concrete is resisted by the form ties. Overturning moments and other lateral forces are resisted by the steel framework by cantilevering from the anchor brackets in the previous pours. After the pour is completed, (figure 3.5d), the sequence is repeated for the next lift.

3.2.2 Load Transfer

As can be seen from the previous discussions, there are significant differences in the operation and in the support system for the two unitized jump forms; one common feature is that the walkways are interrelated with the forming and moving systems. Thus, the safety of personnel is directly related to the design and operation of the whole system, including the tower itself. For this reason, the entire (global) construction system should be considered in trying to understand the load paths within the system.

Under OSHA Construction Standard 1926.451(a)(7) [16], scaffolds are to be capable of supporting without failure at least four times the maximum intended load. Although the possibility of misinterpretation exists [6], the term "intended load" implies an "unfactored load" which is the "design working load" and should be interpreted in that light. The provision is not intended to mean the entire (global) system be designed to support four times the intended system load, but rather, that the system be capable of supporting the scaffold and four times the intended scaffold loading. Some of the components of the system function only as scaffolding or scaffold supports; other components provide support to the scaffolds in an incidental manner. For example, if a component of the structure provides incidental support to the scaffold, it should be capable of supporting at least four times the intended load of the scaffold and still offer enough additional reserve to resist other specified loads with the margin of safety prescribed by the appropriate code.

Prior to performing any inspection, compliance officers should review the manufacturer's drawings to determine criteria for the operation of the system, including design calculations as required by ANSI A10.9-1970 Sect. 6.2.2. Checklists are presented in appendices D and E to assist the officers in conducting inspections. Specialist-consultants may need to be retained for complex systems.

The safety compliance officer conducting the inspection need not have intimate knowledge of the load transfer mechanism, but should be able to recognize gross inadequacies in member sizes and connections when these are at variance with contract documents. Similarly, the compliance officer should be suspect of certain signs of overloading or under-capacity in members and components. Such signs shown by the form systems may include bent or fractured bolts and pins, worn or peened holes, bent or twisted members, excessive or repetitive repairs, cracked or split wood, excessive deflections, swaying, and other similar indicators. Since the tower itself serves as a component part of the overall system, it should also be examined for signs of distress such as severe cracking, excessive honeycombing, or crumbling concrete.

It is not practical to show detailed analyses of the load paths in the space of this manual, especially when considering the degree of variations possible with the form systems employed. However, tables are presented as a reference in appendix C to show the capacities of bolts and pins and to give the approximate number of bolts (according to size) required per 100 ft² (9.3 m²) of scaffolds or forms. These tables should provide the compliance officers with a feel as to whether the system or connection being considered appears adequate or not. Specific analysis of the structure involved must be performed to define the exact distribution of loads and forces.

The following discussions point out certain areas of the jump form systems that can be critical and which should receive attention by compliance officers. Other related items have been previously summarized [1].

System A

There are numerous detailed checks which could be performed on the gangs and all of their components, but the compliance officer should be aware of the general condition of the system, the maintenance performed routinely, the daily inspection procedures, controls used for concrete batching, placement, and curing, installation of embedded anchors, training provided for personnel, supervision, etc. (refer to checklists in appendices D and E). The compliance officer should first observe the location of supplies and materials to be certain overloading is not caused by them, the pathways for access and egress, to be sure they are available at all times, the distribution of personnel on the scaffolds, the placement of concrete, and other related activities in order to obtain a general insight into the ongoing activities. More specific items can then be observed and recorded.

Certain bench marks are established for each phase of the construction; the observance of these is important and should be adhered to at all times. Some of the bench marks may be set by the manufacturer of the form system; still others

may be set by special operating conditions or by codes (such as section 2606b of 1979 Uniform Building Code; section 6.2.1 of ACI 318-77; and section 6.4.7 of ANSI A10.9-1970). All personnel concerned with the construction should be made aware of the minimum criteria and operating standards for the phase of the work in which they are involved. Bench marks most likely to affect the safety of the workers are noted below with the appropriate phase of the construction:

1. Concrete batching, placing, and curing - Job records and field observations for the various concrete activities should be reviewed to be certain that specified conditions are being met in all respects. For example, minimum compressive or tensile strengths may be specified before loosening or stripping of the forms can commence; procedures should be established to be certain the required strength measurements are actually taken and approval granted prior to commencing the activity. Since the form system is anchored to the tower shell and depends totally upon it for foundation support, it is quite necessary that expected strengths are actually realized.

With regard to the evaluation of in-place concrete strength, attention is drawn to the ASTM C900-78T, Standard Test Method for Pullout Strength of Hardened Concrete. An updated version of this test will appear in the 1982 annual book of the ASTM Standard. The test is gaining acceptance by the construction industry as a basis for moving forms. Its use, however, is still voluntary at this time.

2. Moving inside raisers up - As previously stated, during this phase of the activity, the raisers are suspended from the forms against the previous day's lift. It is of utmost importance that no ties or anchor clamps be removed from the forms prior to re-anchoring the raisers in their new position. This can be a critical operation since the overturning moments caused by the raisers apply the first external load to a new lift of concrete at a time when it has a relatively low strength.
3. Moving outside raisers up - Like the inside ones, the outside raisers are suspended from the forms during the move and no form ties or anchor clamps should be removed from the set of form panels until the raisers are up and securely anchored.
4. Moving inside forms up - This phase is one of the most critical, since all form ties are removed and cantilever reactions from the raisers apply their loads primarily to one level of anchor bolts set in 2-day concrete. Proper embedment and installation of the anchor bolts are essential and cannot be underestimated. One of the worst conditions occurs on the first lift constructed with the forms, due to the maximum slope of the shell (with respect to vertical); but the thickened wall provides better strength for the anchorage embedment. A lift near the base of the tower, but with reduced wall thickness, probably is worst from the standpoint of loads on the embedment.
5. Moving outside forms up - As above, this portion of the cycle is critical and should be carefully inspected for proper anchor bolt installation and

thread engagement. Due to the supporting action of the raisers during concrete placement in the inclined webs, the bottom anchor bolt in the outside raisers is most severely loaded in the first lift of the tower. The top anchor bolt probably does not realize its maximum load until the last lift, when the slope of the tower (with respect to vertical) reaches its maximum negative value.

6. Anchorage embedments - The careful construction and placement of embedments for the main anchor bolts is very important since the proper action of the anchors is so critical. The procedure should be part of the specifications in the contract documents kept at the job site. Particular attention should be given to positioning the embedments correctly and in consolidating concrete around them.

System B

As noted in the previous discussion, there are some general items with which the compliance officer should become familiar. He should be able to observe the overall construction operation in order to get a feel for the procedures in use. He should check against the specified bench marks and note those areas of unsafe practice. Items of particular importance to worker safety are stated in the following with the corresponding phase of the construction.

1. Concrete batching, placing, and curing - Like the requirements for system A the attainment of minimum required strengths and conditions for concrete are very critical to the overall system because the loads and reactions of the form system are taken directly to the tower shell.
2. Stripping forms - As stated previously, stripping the forms leaves the gangs suspended from a single level of anchor brackets. It is of utmost importance that the anchor bracket is not released at any time until the next lift has been completed and new anchor brackets are installed and anchored.
3. Moving jacking frames up - This is another critical time since the loads are supported at only two locations. Care should be exercised in placing anchor brackets at the next position to ensure that the anchor bolts are fully engaged.
4. Moving forms up - Just as with system A, this phase is one of the most critical since all loads are borne by newly placed anchor brackets in the youngest concrete, which is 2 days old. It can also be seen that the worst anchor loads will be at the first lift of the inside forms, near the base of the tower. The anchor for the outside forms probably receives its greatest load on the last lift of the tower.

3.2.3 Access and Egress

The scaffolds provided with the respective form systems described thus far do not differ significantly in their features, but some of their details present different problems.

System A

When all gangs are set in position to pour, there are two levels of continuous walkways on both the inside and outside gangs. These provide lateral access to all areas of the tower lift under construction. A separate, small work platform is provided at the base of every raiser to furnish personnel a place to work when installing, inspecting, or removing the lower anchor bolts.

Access from the outside forms to the inside forms is easily accomplished by stepping over the small projection of the forms, since the walkways are mounted near the top level. Access between scaffold levels is by ladder. Since the pitch of the cooling tower wall changes continuously, ladders having a negative pitch are sometimes encountered. The use of such negatively inclined ladders should be avoided because they do not provide a sufficiently firm foothold and tend to impede expedient access between work platforms at different levels. From the top platform to the intermediate level, a permanent ladder is provided at the center for each gang (an average distance of about 35 ft (11 m) between ladders, both the inside and outside). To the lower platforms, a permanent ladder is provided at every raiser. Hatches in the walkways give access to the ladders at each level; hinged hatch covers prevent workers on the walkways from falling into open hatches.

During the moving cycle, the rings of scaffolds are interrupted since the form gangs are moved independently. This phase presents a safety hazard due to the uneven levels at the ends of each gang. Because of economic and equipment reasons, the gangs are usually moved up individually a full lift distance of 6 ft (1.8 m) in a single move. This can leave a 6-ft (1.8-m) distance between adjacent platform levels which should be guarded to comply with OSHA regulations (1926.451 and 1926.500, ref. 16). The movement of gangs also alters the normal paths for access and egress. In the event of an emergency evacuation of the form system, some workers would be delayed by detours at the uneven sections. There will be, however, one general access/egress way of travel which will change according to the stage of moving. These should be continuously kept free of impediments for instant use in case of an emergency. Existing OSHA regulations do not require that the means of access and egress be provided by the same path at all times. Therefore, adequate training of personnel, including emergency evacuation procedures at the various stages of moving, is required to assure their safety.

The most common means of access from the ground level to the working level of the forms is by a stair tower consisting of open cage sections lifted by crane hook and mounted on the outside of the cooling tower. These generally follow the slope of the tower. Some projects make use of cranes to deliver the workers to the level of the forms, due to the time involved in climbing stairs to the higher elevations. This mode of delivery should comply with OSHA construction safety regulations (sections 1926.451 and 1926.550, subject to the interpretation of OSHA STD 1-11.2, ref. 16).

The safety provided by stair towers is affected by their construction, anchoring, bracing, density of use, and fall protection enclosure. A typical stair tower at a cooling tower will follow the contour of the shell in order to

provide maximum bracing and easiest access at the level of the forms. Tube-and-coupler sections of scaffolding are required to properly follow the contour and provide horizontal landings for the stairs. However, stair towers having inclined landings are sometimes encountered, and often they are not equipped with toeboards. In addition, frequently fall protection covering is either not used, or, if used, consists of poultry netting which is structurally ineffective in impeding a fall in progress. The provision of horizontal landings, toeboards or more substantial enclosures, such as prescribed by OSHA for caged elevators, will substantially mitigate fall hazards from accessways, especially in the case of an emergency evacuation. It should be noted that OSHA regulations [16] require the use of toeboards on elevated work platforms and scaffolds, and accessways serving these areas may be interpreted as being subject to the same requirements. Sound footings are clearly required for the scaffolds due to the extreme heights reached by the stair towers and the correspondingly high loads at the base of the tower.

Design working loads for the walkways and work platforms on the forms are specified by their intended usage as determined by the manufacturer and user. ANSI provisions (ANSI A10.9, section 6.2) state that an allowance shall be made for live loads. OSHA (1926.451(a)[16]) specifies that a safety factor of 4 be maintained on "maximum intended load" which, as noted earlier, is interpreted as the design working load. The normal light scaffolding working load of 25 psf results in a total calculated working load of about 300 kips (1340 kN) when applied uniformly over the two walkway levels for a moderately sized tower of 300 ft (92 m) in diameter. This results in a 5-kip (22-kN) allotment for each of the 60 workers that might be employed on a tower of that size. Such an amount is completely unreasonable to anticipate. Therefore, it should not be a design requirement to allow for 100 percent utilization of the working load on the total system. However, individual gangs of forms should definitely be designed to support the design working loads; in addition, anticipated localized loading from supplies or equipment needs to be considered. Such extraordinary load considerations should be stated in the project/equipment drawings, and the compliance officer should be certain that the loads are not being exceeded.

Requirements have not been established for structural design conditions that would result from the emergency evacuation of form systems such as these. The Uniform Building Code [7] requires clearly marked exits in public buildings at distances not exceeding 150 ft (45 m) from any point of public use of the building. In open parking garages, this distance is extended to 250 ft (76 m) presumably due to better visibility and access. It may be reasonable to establish a similar requirement in the construction industry, modified according to the type of activity and potential threats to personal safety. In the case of cooling towers being built as discussed thus far, certain strategic locations could be established around the circumference of the tower to provide additional safety from temporary environmental hazards. Such locations could be separate from the regular form gangs or could be special gangs modified to a type of fail-safe condition. The basic principle of the unitized gang concept reduces the risk of the type of chain reaction experienced with the integrated type of jump forms discussed in section 3.3 and other publications [8, 9, 10].

The design of a specified "safe location" should consider all potential conditions which could be expected to occur. For instance, if the maximum number of workers on a given tower all gathered in a specific location, the live load applied would be about 50 psf (2400 Pa) for normal spacing of the workers, 100 psf (4800 Pa) for crowded conditions, and possibly 150 psf (7200 Pa) for emergency crowding. Therefore, a design load of 150 psf (7200 Pa), with an adequate margin of safety, should be satisfactory for the specified locations. The design should carefully consider the whole system including all connections and support conditions. Special or additional reinforcing might also be required in the adjacent tower shell to resist the additional design loads.

The concept of "safe locations" noted above presumes the availability of a sufficient number of readily accessible shelters so that most workers will find quick refuge ahead of an advancing collapse. Whether this scheme will turn out to be effective or economically feasible remains to be explored.

There seem to be no direct alternatives to fully compensate for environmental constraints on accessways in jump form systems. Furthermore, if a workable scheme can be developed, its application in the field will have to be on a voluntary basis, "to meet the intent of OSHA safety regulations" [16], which do not specifically address the problem. However, industry has been able to cope indirectly with the problem of confined work spaces which are not unique to jump form systems. This has been achieved through strict quality control measures to minimize the risk of collapse to acceptably low levels. In the case of jump forming systems, the item of singular importance is the need to control the quality of concrete in the shell which supports all of the construction loads. The basis for the enforcement of strict quality control for concrete is the key provision contained in the OSHA regulations (sect. 1926.701(a)(4), ref. 16) which states that "Imposition of any construction loads on the partially completed structure shall not be permitted unless such loading has been considered in the design and approved by the engineer-architect". In effect, any partially cured concrete component which supports construction loads should be designed with a minimum factor of safety of four stipulated by OSHA (section 1926.451(a)(7), ref. 16).

System B

Similar to the previously described jump forms, the individual gangs provide continuous walkways around the tower circumference when set in the pouring position. There are three levels of continuous walkways with an intermediate work platform on each gang. Due to the bracing pattern and adjusting features, access on the walkways is more restricted than for System A.

Also due to the construction of the steel frame, the guardrails for all but the top walkway are not vertical; they are parallel to the tower shell. Therefore, the guardrails for the inside forms slope away from the workers while on the outside, they slope toward the workers. Although the existing regulations do not require guardrails to be mounted on vertical posts, the use of inclined rails detracts from the worker's feeling of security. In the event the guardrail needs to be inclined outward for practical reasons, such as not to impede access or interfere with lifting of forms, the spacing between rails may need

to be narrowed and rails, posts and anchors be made sturdier to meet the intent of OSHA regulations for guardrails (assumed vertical). In addition, toeboards should always be employed.

Access from the outside forms to the inside forms is easily accomplished when the forms are in the pouring position, but access is severely restricted with the forms in the stripped position. The gap between the inside and outside prevents stepping from one to the other; a section of each top scaffold is also hinged upward to allow form stripping and it restricts movement while in that position. During the same time when forms are stripped, lateral access on the second scaffold level is more restricted than normal due to the bracing and stripping mechanisms. Vertical access between the various scaffold levels is by ladder at intermittent locations, not at every gang. The exact distance between ladder access points is not fixed, but the compliance officer should observe their locations in comparison with requirements for access and egress.

When the form gangs are being moved up to the next lift, there are interruptions in the lateral access around the scaffold rings. Like system A, the gangs can be moved up a full lift in one cycle, but the equipment is more easily adaptable to moving in a series of 1-ft (0.30-m) steps. Such movements do not severely hamper access between adjacent gangs like the other system discussed. Hinged sections of scaffold connecting the ends of adjacent gangs assist in providing continuity to the walkways.

As previously noted, a common means of vertical access from ground level to the working height of the forms is by a stair tower. System B has also been used with a personnel elevator servicing the forms. This presents a problem of bridging the variable distance from the sloping tower shell to the vertical elevator tower; landings for the elevator also apply additional loadings to the form system and tower shell. Inspection of such systems should include assurance that the extraordinary loadings have been approved by the engineer for the particular cooling tower under construction and that any required additional reinforcement has been properly installed.

No special provisions are known to have been made in regard to rapid or emergency evacuation of the form system. Again, the use of the individual gangs is designed to prevent a chain reaction occurrence which could cause the whole system to fail. Therefore, the same discussion about a specified "safe location" and strict maintenance of adequate safety margins for the concrete can apply as presented for system A.

3.2.4 Critical Safety Items

Although systems A and B differ in many respects, their basic similarities result in the same critical safety items. These items are universal in application to jump form systems and should be of highest priority for safety inspection. The following items highlight those phases of the construction activities which should receive the greatest attention:

1. Concrete - The concrete in the tower must provide support for the overall system. Procedures and records should confirm that the batching, placing, and curing of the concrete mix is resulting in the required strengths. Since the tower shell serves as a foundation for the complete forming system, it must be of sound and predictable quality.
2. Anchorage - The attachment of the form system to the tower shell serves as the vital link between the forming system and its foundation, the tower shell. Full and complete design, fabrication and installation of the anchors and all related components must be assured in order to provide a safe working environment. It is unacceptable to allow use of inferior or under-capacity components or to allow omission of any anchorage units.
3. Form Ties - Due to the large hydrostatic pressures in the forms, ties are necessary to prevent distribution of the hydrostatic loading into the cantilevered components. Such loading would probably overload those components, including the anchorages. The placement of form ties should be in accordance with the form design specifications.
4. Movement of the Form System - A critical time in the construction cycle occurs during the moving phase. Since minimum anchorage points are in use, there is less redundancy in the structural system at a time when some of the imposed construction loads are highest and concrete strengths are lowest.
5. Chain Reactions - One basic principle of the unitized jump forms is their ability to stop a chain reaction failure initiated by the failure of an individual element (i.e.: gang). There should not be additional appliances or auxiliary items which interrupt this ability. For instance, if safety nets are installed, they should be in discrete units to prevent linkage of all forms into a common unit. Other items may need to be continuous across all gangs (e.g., air or water lines), but can be equipped with "break-away" connections in the unlikely event a complete gang were to fail.

There are many individual items which may be critical as related to personal safety, but the more important ones are noted above. Inspecting officers should be trained to identify gross inadequacies or signs of structural distress in order to help protect against catastrophic failures involving the life safety of many workers. When those items are adequately checked, the more detailed checks relating to the safety of fewer workers can be made.

3.3 SELF-RAISING INTEGRATED JUMP FORM SYSTEM

This jump form system is used most commonly in cooling tower construction in the U.S. and has also had the most catastrophic failure [8, 9]. Extensive investigations have shown there is a complex inter-relationship of the tower forms, and hoisting system [2, 10]. Detailed descriptions of the system are provided in the referenced publications and will not be repeated in this section. A general description should be adequate to provide a basic understanding of the system components.

3.3.1 System Description

The whole forming system is composed of multiple units integrated into a double ring of forms, scaffolds, and related items. When moving from one lift to the next, all inside and outside units are moved simultaneously. A procedure that has been used for delivery of concrete and other materials from the ground to the working level of the forms utilizes special frames (cathead gantries) at six equally spaced positions around the circumference and mounted on the form system to support the hoisting lines (figure 3.6). As confirmed by extensive analyses, the cathead gantries can apply extraordinary loadings to the tower shell and form system. Limiting the loadings involves careful planning and supervision (section 3.4).

Besides the cathead gantries, there are four basic components to the form system, all interrelated (figure 3.7). The first, placed at equal intervals of about 10 ft (3 m) around the circumference, is a series of specially made beams called jumpform beams, attached vertically to the wall with two anchor bolts in each lift (figure 3.6). The beams are 20 ft (6.1 m) long with a splice at the center to allow the 10-ft (3.1-m) pieces to be alternately "leap-frogged" above one another as construction continues up the tower shell. Jumpform beams are located on both the inside and outside faces of the tower, directly opposite one another. Anchor bolts connect the inner and outer beams through a threaded anchorage in the tower shell. One flange of each beam actually serves as a forming surface for a portion of the shell.

The second basic component is a climbing frame (figure 3.7) which attaches to the jumpform beams with a series of guide wheels. A twin-pawl ratchet system in the climbing frame is incorporated to grip welded lugs on the beam (insert, figure 3.7); one pawl is activated by a hydraulic cylinder and the other is spring loaded to act as an automatic safety stop.

The third component is the actual forming portion, comprised of plywood facing backed up by horizontal, adjustable steel joists. The joists and plywood form the section of shell between the jumpform beams; each end of the joists frames into a vertical stiffback adjacent to the jumpform beams. Removable wedges connect the stiffbacks to the jumpform beams and transfer lateral loads from the hydrostatic pressure directly to the beams. Therefore, the anchors for the jumpform beams serve as form ties during concrete placement, in addition to their role as support for the system.

The fourth component is the scaffold system, which consists of four levels of scaffolds suspended directly from the climbing frames (figure 3.8). Planking spans the variable distance between the climbing frames. Safety netting is suspended from the top walkway level to the fourth level.

A daily construction cycle is as follows (figure 3.8):

1. Forms are released, cleaned, and adjusted for geometries in the next lift. Because of the fact that the anchors in the jumpform beams serve as form ties and as cantilever anchors, they do not receive new or additional loads when the form are released. This phase does not represent a critical structural condition.

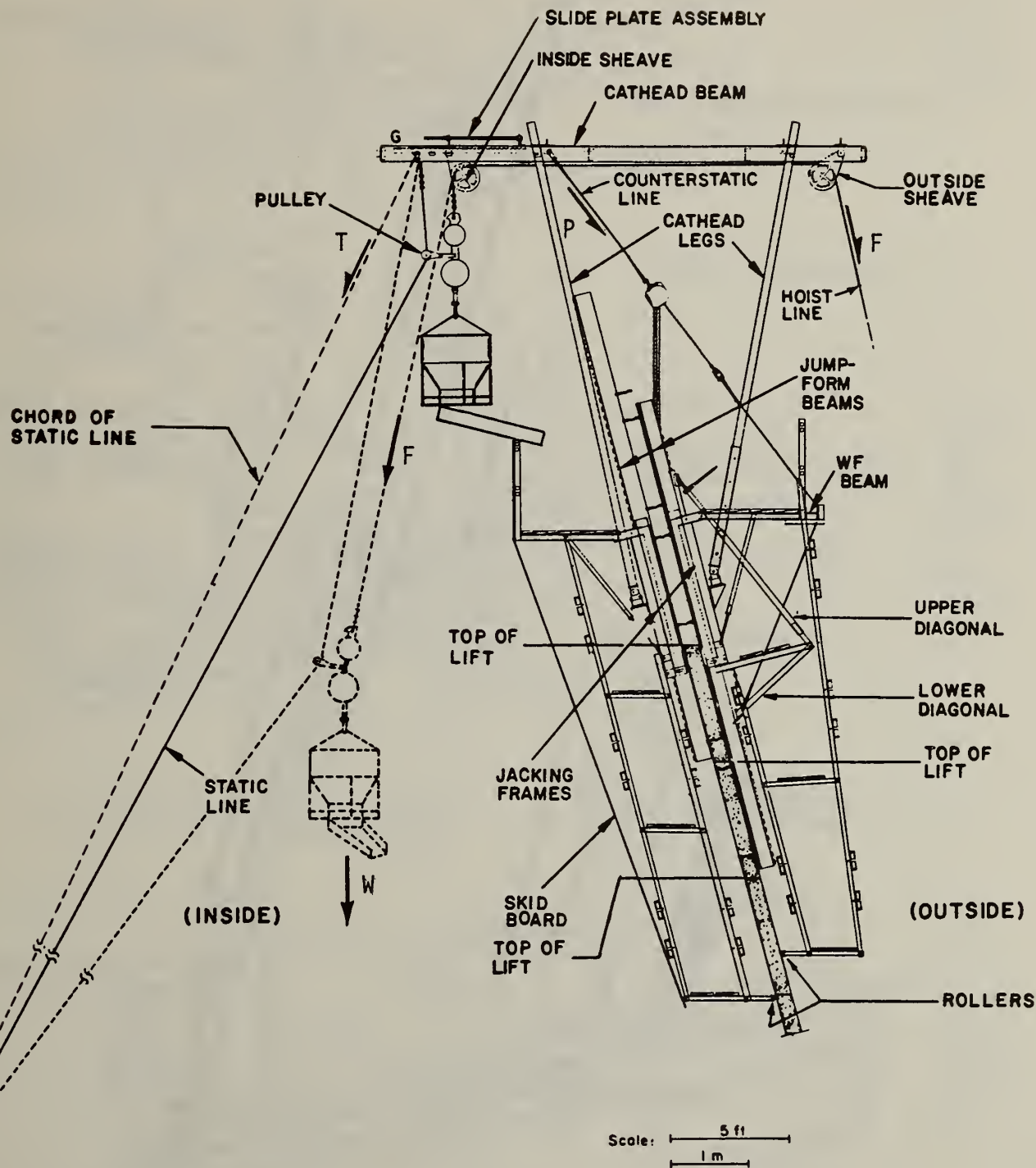


Figure 3.6 Integrated jump form system and hoist mechanism

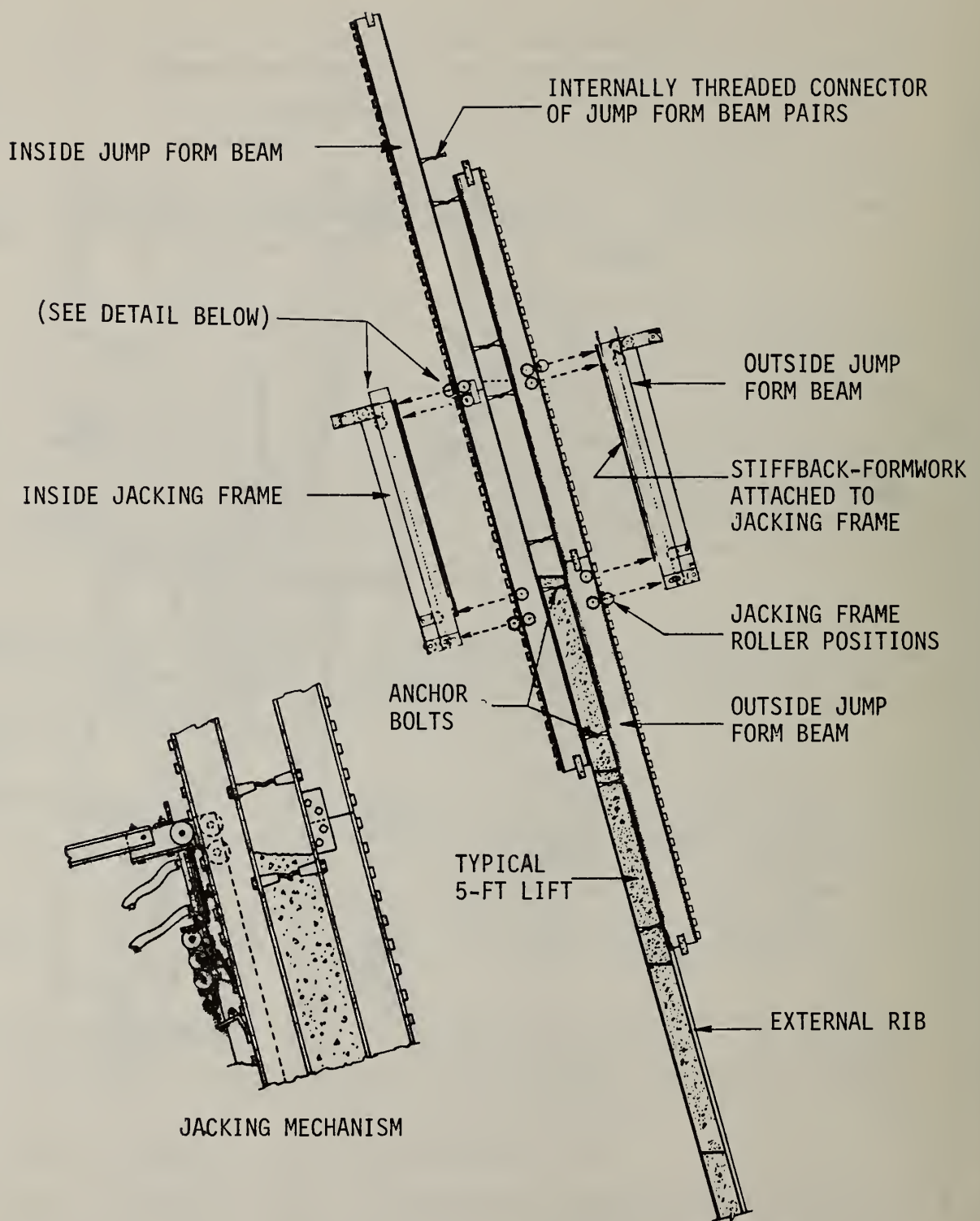


Figure 3.7 Basic components of integrated jump form system

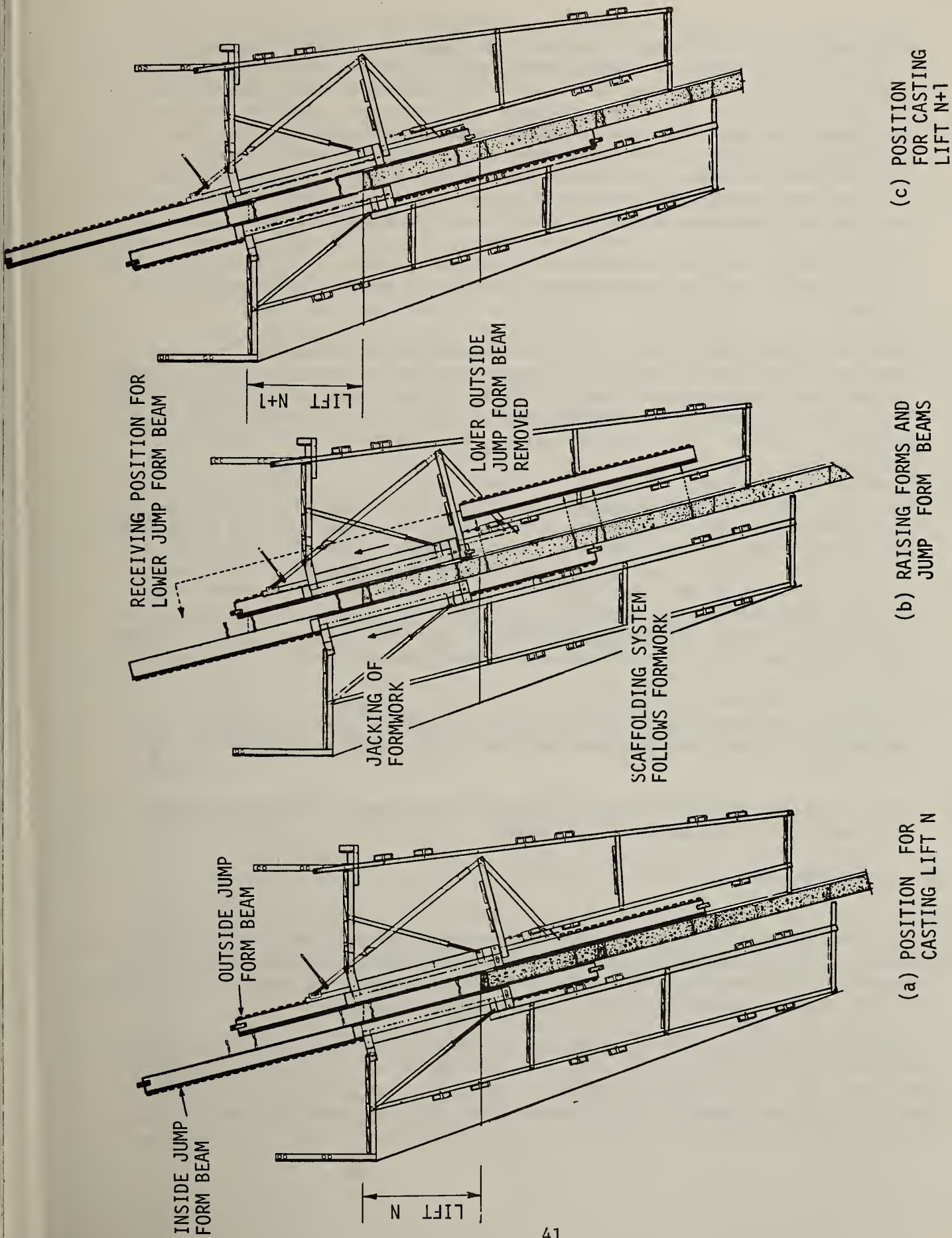


Figure 3.8 Construction cycle of integrated jump form system

2. Cylinders in the climbing frames are activated and the entire form and scaffold system, both inside and outside, is moved upward a distance of 5 ft (1.5 m) in small increments corresponding to the lug spacing on the jumpform beams. During the move all of the jumpform beams remain anchored to the tower shell; the climbing frames and attached scaffolds progress up the beams. As with the other jumpform systems, the beams act as cantilevers in supporting the forms and scaffolds and, again, the anchor bolts receive their largest tension loads due to overturning moments during the move. The jobsite procedure is to install anchor bolts connecting the inside and outside jumpform beams above the lift, thus allowing both beams to act in unison in resisting the movements. However, due to the splice at midheight of the beams, there are positions on alternate lifts of the form which have only one of the beams resisting the overturning moments and other lateral forces.

Since the upper anchor bolts for the beams initially serve as form ties, they are effectively preloaded to some force, which may be enough to resist tensile loads caused by the moving loads. If not, it may be found that the beams move slightly away from the shell when the extra loading exceeds the preload condition. An involved analysis is necessary to determine exact loading.

3. The lower halves of the jumpform beams are removed and transferred to the top end of the upper half, where they are spliced again to form a continuous run of beam. Once installed at a given elevation, the anchor bolt/form ties are not released until two full lifts of concrete have been placed and the climbing frame has completely cleared the respective beam half. Load-bearing beam halves may have 2, 3, or 4 anchor bolts in place at any one time, depending on the exact phase of the construction cycle. No less than 2 bolts should be in place on all load-bearing jumpform beams at all times.
4. Additional adjustments must be made to the cathead gantries prior to beginning the hoisting of materials due to the changing geometry of the tower shell.
5. When forms and reinforcing are positioned and geometry checks completed, the next lift of concrete may be placed.

3.3.2 Load Transfer

As previously noted in section 3.2.2, the entire construction system needs to be considered when developing an understanding of the load paths within the system. Because of the involved interrelationships of the components of the integrated forming system, the scaffolds must be viewed as a part of the overall system and should not be inspected as a discrete element.

As with the other jump form systems, it is not necessary that the inspecting compliance officer be concerned with the detailed load path and load transfer mechanisms, but it is desirable that the officer be capable of recognizing signs of distress or potential distress. Many of the comments presented in

other sections with respect to checking the overall (global) system also apply to the inspection of this system. Appendix C may be used to develop a feel for the general adequacy of connections.

Certain bench marks must be observed during every phase of construction; the complex relationships require that the workers be made aware of the minimum standards for the activities in which they are involved. Supervisors must be cognizant of the effects caused by deviations of one component upon other components. Bench marks most likely to affect the safety of workers are noted below with the various items of construction.

1. Concrete Strength - Since the forming system depends totally upon the partially completed tower shell for support, the strength of the concrete must be as specified by the form manufacturer and/or owner for the various lifts at each phase of construction activity. Job records should be checked by the compliance officer to insure that the specified strengths are being obtained. Procedures in effect should be such that prescribed strengths are measured and approved prior to continuation of activity.
2. Placing Concrete - This phase makes use of the cathead gantries to deliver buckets of concrete from ground level to the working level of the forms from where hand-propelled carts (i.e.: Georgia buggies) transport the mix laterally for placement in the forms. The rigging on the cathead gantries and the hoisting operations create critical forces on the form system and tower shell, as highlighted in section 3.4.

Distribution of concrete with Georgia buggies is unique to this system. It introduces a certain amount of dynamic loading to the forming/scaffolding system, but should not materially affect the integrity of the overall system. Because of the dynamic effects, connections of the scaffolds should be checked more frequently than normal to assure their adequacy. Additional care needs to be taken in the joining of scaffold planking between adjacent form units in order to provide a smoother working surface for the Georgia buggies.

3. Stripping Forms - As previously noted, this phase does not cause new or additional loading to the anchor bolts and, therefore, does not represent a critical structural situation. Precautions should be taken to assure that the stripped form sections and wedges are secured to prevent injury from falling pieces.
4. Moving Form System - This phase of the regular cycle is the most critical. Particular care must be taken to insure that the hydraulic cylinders in all climbing frames are engaged with the lugs on the jumpform beams. Jumpform beams should be inspected for damaged or missing lugs; any needed repairs should be made immediately. Safety pawls should be inspected to be certain they are in proper working order; needed repair or replacement should be made immediately.

As the form system advances up toward the next lift, the distribution of loading on the anchor bolts continually changes. The overturning loads are

gradually applied to anchor bolts in the younger lifts. When the climbing frame crosses the jumpform beam splices, the loads are applied for the first time to new sets of anchor bolts. Procedures should be in effect to insure that all anchor bolts are securely in place on any jumpform beams which are carrying loads from the climbing frames. A minimum of two anchor bolts in hardened concrete are required on all loadbearing jumpform beams; the size should be as specified by the form system manufacturer and/or owner.

3.3.3 Access and Egress

Since the four levels of scaffold on the integrated jumpform system are attached to the climbing frames, the movement of forms from one lift to the next does not interrupt the normal access around the tower circumference or between the various levels of scaffold. The four levels provide continuous access around the inside and outside surfaces. The two lower levels are used to recover the bottom jumpform beam sections, patch the anchor bolt holes, and make any necessary repairs to the tower surface. The second level is used to work with the form section between jumpform beams, during stripping, adjusting and resetting of the forms. Access between lower levels at opposite sides of the tower is difficult. However, the type of work conducted at these levels eliminates the need for frequent crossover. The top level is used for the main access to various points on the tower and for placement of concrete and rebar in the lift under construction. Restrictions to personnel evacuation exist at the six cathead gantry locations; in the event of an emergency evacuation, these could cause delays.

The concept of a "safe location" cannot be readily applied to this system due to the integration of components. A chain reaction failure that occurred in the past showed the significance of the failure of an element in relation to the whole system. Once there was a failure at one location, the interconnected components were unable to sustain the additional load caused by the local failure and subsequent progressive failures occurred until the entire system had collapsed. In order to provide "safe locations," discrete elements must be utilized to prevent the occurrence of progressive failures; connections between the "safe locations" and the balance of the system must be incapable of transmitting failure loads to the safe area. Also as discussed in section 3.2.3, special reinforcing may be required in the tower shell wherever "safe locations" are designated.

The typical means of access and egress between ground level and the forming system is by a stair tower on the exterior of the cooling tower. The stair tower follows the contour of the shell, with braces attached at intermittent levels. Additional stair tower sections are added in increments as construction of the cooling tower progresses. Personnel utilizing the stairs may be discharged onto one or more levels of the outside form scaffolds, from where they may move laterally to other sections or vertically to other scaffold levels. Precautions are necessary during the time of form system movement due to the changing elevation differences between the scaffolds and the stair landings; safety barricades and/or signs should be in use at that time.

As discussed earlier, the scaffold design loadings are not specified by regulations but rather by their intended usage. The four levels of scaffold used in the integrated form system have different uses and, therefore, different loading criteria. The top level on the inside forms is used for the distribution of concrete and reinforcing steel; load concentrations can develop if materials are stockpiled or if loaded Georgia buggies are too close together. Inspecting compliance officers should ensure that any load concentrations do not exceed the form system manufacturer's design assumptions.

The other scaffold levels are primarily subjected to normal personnel loadings, except where equipment or materials may be stockpiled. Since the lower levels of scaffold are partially used for patching of anchor bolt holes and tower shell concrete, water and cement grout materials are temporarily stored on the walkways. Heavy load concentrations can develop and should be checked for compliance with the design.

3.3.4 Critical Safety Items

There are numerous elements in the integrated jump form system; because of the unified construction and the risk of a progressive collapse, many elements are of major importance. Great care must be taken by the workers and supervisors to insure that all components are properly installed and are used in accordance with the design criteria. Those items which should receive the most attention are as follows:

1. Concrete - Since the tower shell is such an integral part of the overall support system, jobsite procedures and records should show that the concrete can and does attain the strengths required at the various phases of construction. The concrete must be of sound and predictable quality.
2. Anchor Bolts/Form Ties - The jumpform beam anchor bolts initially serve as form ties to resist hydrostatic pressure of fresh concrete; subsequently, they serve as a vital link between the whole forming system and its foundation, the tower shell. Every anchor bolt is of significant importance, it is unacceptable to allow the omission of any anchor bolts or the use of any inferior components.
3. Movement of the Form System - This phase of the construction cycle represents different critical situations. As the climbing frames progress up the jumpform beams, the overturning moments and form system loads are applied to new anchor bolts and younger lifts of concrete. Personnel training and procedures must be adequate to insure that all required anchors are in place on all jumpform beams and that any damaged or missing lugs have been repaired. The risk of progressive collapse is too great to allow the use of inferior elements or to allow omission of any anchor components.

Although the integrated jump form system is composed of hundreds of elements, the areas noted above should provide inspecting compliance officers with those of most importance. It is most desirable that the inspectors identify gross inadequacies or signs of structural distress affecting the life safety of many workers. Detailed or spot-checks affecting fewer workers can be made after the major sections have been examined.

3.4 FLEXIBLE HOISTING SYSTEM

One of the methods for delivering concrete and other construction materials to the top of the cooling tower utilizes a system of cableways which generally requires a high level of training and expertise in the field to keep the tower from being subjected to hoisting overloads. The following sections identify the principal aspects of the system that are most critical to the maintenance of a safe working environment.

3.4.1 System Description

The concrete and other construction materials are delivered to the work platform at the top of the partially completed tower by means of a drum-actuated hoist line which pulls the cargo along a stationary cable (or "static line") on an inclined trajectory, as shown in figure 3.6. The top of the static line is anchored to a cathead installed at the top of the shell and equipped with sheaves to guide the hoist line. The base of the static line is attached to a grip hoist which is anchored to the ground.

Usually several hoist lines are operated simultaneously to allow completion of one lift within the work day. Concrete is usually delivered in 2 cu yd (1.6 m³) capacity buckets to the top interior work platform and transported to the forms by hand-propelled carts (i.e., Georgia buggies). The catheads are attached to climbing frames which ride the jumpform beams during the lifting phase. Usually there are 40 to 60 workers on the scaffold depending on the size of the tower. They are mostly found on the top platforms, particularly the inside platform, when casting is in progress.

3.4.2 Load Transfer

It has been shown that the system described above can create local stresses in the tower shell well in excess of those attributed to all other loads combined [2, 10]. The mechanism by which hoisting loads are transferred to the tower is a complex subject which has been fully addressed in reference 2. Briefly, the hoisting loads may be visualized by consulting figure 3.6 which identifies the principal forces on the cathead attributed to payload W at the end of the hoist line (gross weight of concrete bucket in this case). Tension T in the static line is the major source of overturning moments which tend to pull the shell inward. The two forces F in the hoist line contribute mostly to the downward load on the shell while the cathead-stabilizing chain hoist develops a force P along its axis. These cathead forces are transmitted through the system of climbing frames, jumpform beams and interconnecting anchor bolts to (mostly) the top lift of the shell. The concrete in this lift would be one day old or younger if the rate of construction is one lift per day.

3.4.3 Critical Safety Items

A thorough understanding of the force transfer mechanism is a necessary precondition for checking the safety of the hoisting system. It must be emphasized, that without strict observance of the proper installation, adjustment, operation and maintenance procedures during each construction cycle, the

hoisting system can become a wrecking mechanism for the tower. This is so because slight deviations from certain specified procedures, such as overtightening the static line, can cause substantial increases in the loads the hoisting system transmits to the tower.

In view of the intricacies noted above, a comprehensive set of job-oriented hoisting specifications prepared by the designer should be kept at the job site and the contractor should maintain a continuous record of compliance with the benchmarks spelled out in those specifications. Benchmarks most likely to affect the safety of workers are noted below.

1. Movement of Form System - This phase of the construction cycle should not create unusual hoisting loads on the system if the proper procedures are followed. Before the jacking frames are raised, there should be sufficient slack in the cables to keep them from becoming taut. The static line can be slackened by releasing the grip hoist at its base by a predetermined amount. The hoist line can be kept slack by keeping its end free of any loads or by releasing the brake at the drum. In the event the cathead is pinned at its supports, it may be necessary to tie it down before the static line is released to keep it from becoming rotationally unstable.

After the forms are raised, the cathead is realigned by means of the chain hoist. The static line is then retensioned by means of the grip hoist. Sometimes the cathead beam is equipped with a slide plate assembly to adjust the static line from the top as well.

The proper readjustment of the static line is perhaps the most critical step during each construction lift cycle requiring strict compliance with the hoisting design specifications. The maximum tension in the static line (T in figure 3.6) under a given load increases rapidly with the initial tension in that line under no load. The designer's specifications should contain precise instructions for the proper calibration of the static line tension for every lift.

2. Delivery of Materials - Upon completion of the hoisting system setup for the new lift, but before delivering materials to the top, it is advisable to run a routine visual inspection of system components (chain hoist, cables, sheaves, cathead, connections, grip hoists, drum, etc.) in accordance with a standard checklist of items (appendix D) based on ANSI A10.5 Standard for Material Hoists [18]. This would be the appropriate time to detect any misalignments or damaged components and to carry out needed repairs and replacements in accordance with the maintenance procedures stipulated by the Code and manufacturer's recommendations.

The operation of the hoisting system should comply with the procedures contained in the designer's hoisting specifications and those recommended by the manufacturer. These should spell out such items as the maximum allowable payload and the maximum safe operating speed. They should also contain such other provisions as a built-in safety feature for the grip hoist to avoid accidental tensioning of the static line when the drum is idle, and a fail-safe method to slow down the bucket when approaching its destination at the top to avoid impact against the scaffold or the cathead.

Owing to the engineering complexities of the hoisting system it is recommended that the specific guidelines for its safety inspection documented in ref. 1 be followed. It is virtually impossible for the compliance officer to conduct a complete safety inspection of the premises without the benefit of well-documented field records on hoisting procedures. Normally, these records will be examined first for comprehensiveness and for compliance with bench marks set in accordance with specific guidelines prepared on the basis of an independent evaluation of the system. It is recommended that OSHA uses a registered engineer - specialist to assist the compliance officers in this evaluation. The extent of compliance may then be verified by an independent inspection of the hoisting system, keeping safety priorities in the proper perspective. For instance, it would be advisable to conduct an independent check of the tension in a static line when it is not in use and to witness at least one complete hoisting cycle. This may then be followed by normal inspection of other hoisting components.

4. CHIMNEY CONSTRUCTION

4.1 GENERAL DESCRIPTION

This chapter discusses slip forming systems used in the construction of large chimneys. Such chimneys may have heights of 900 ft (275 m) or more; some have been built to a 2100 ft (640 m) height.

The chimneys under consideration in this guide are basically tapered concrete cylinders. Diameters at the base are usually 40 to 80 ft (12 to 24 m) (but can be more), gradually reducing to a top diameter of 25 to 50 ft (8 to 15 m) [12]. Wall thickness varies similarly, from a maximum of about 3 ft (1 m) at the base to a minimum of 8 in (0.2 m) near the top. After concrete construction has been completed, flue liners may be placed inside to protect the stack from chemical attack or to separate exhaust gases from different heat sources.

The chimneys considered in this guide are primarily in use at fossil-fuel power generation facilities to discharge excess heat and gases into the upper atmosphere. The gases enter the stack through a breach at some point above ground level and rise naturally to the top where they are discharged into the air.

The internal finish of the stacks can affect the flow of gases and the amount of particles trapped during chimney operation. The external finish affects the chimney's wind resistance and therefore, the lateral forces acting on the structure. Alignment tolerances also affect them structurally; plumbness must be within specified limits. The extraordinary heights encountered in these chimneys present challenges to constructors in the form of logistics, tolerances, procedures, and safety.

Tall chimneys use slip forms exclusively; jump forms are not economical at such heights. Precast sections have recently been used to construct stacks to heights of 250 ft (76 m) [11] and are planned for taller structures. However, slipped chimneys are expected to continue their dominance of the larger structures.

Construction of the chimneys begins with a starting ring formed on the foundation with conventional forms followed by installation of the slip form system. Once begun, the slide is continued on a 24-hour basis until the stack is completed. Logistics is a main concern due to the limited access and continuous activity.

4.2 SELF-CLIMBING SLIP FORM SYSTEM

The most common slip form system utilizes an assemblage of elements directly supported by numerous vertical rods embedded in the concrete. Hydraulic jacks connected to the rods are used to lift the entire system by climbing the rods while concrete is placed in the forms.

4.2.1 System Description

As discussed in chapter 2, individual elements of the slip form system are designed to serve multiple functions; a typical cross-section is shown in figure 4.1.

Steel yokes, in the shape of an inverted U, straddle the chimney wall and are spaced at intervals of 4 to 8 ft (1.2 to 2.4 m) around the circumference. The yokes are supported by the steel climbing rods embedded in the concrete walls; hydraulic jacks mounted on the yokes allow the form system to climb the rods during the slipping operation. Additional rod sections are spliced into the protruding ends as the process continues.

Spanning horizontally between the yokes are wooden beams, referred to as wales, to which the form sheathing is attached. Forms are usually about 4 ft (1.2 m) high, but may vary according to the concrete design, curing conditions, and rate of construction. Most often, the form facing is plywood, but may be of other materials, such as finished lumber, steel, or fiberglass [12, 13].

A complete work deck at the top of the forms usually covers the inside area of the chimney; from this deck reinforcing steel is installed and concrete is placed. An optional upper deck may be utilized for installation of vertical rebars, splicing of climbing rods, and other activities. For access to the exterior forms, a perimeter deck is located at the same level as the main work deck.

A hoist and elevator system provide personnel access and delivery of materials up through the center of the stack; support of the hoist system is provided by the steel framework of the work deck and/or the yokes (figure 4.1). Some systems utilize steel A-frames projecting outward from the stack to which hoists are attached, others use personnel hoists mounted on independently supported steel towers.

4.2.2 Load Transfer

Though most of the elements have dual roles, the mechanism of structural support is usually simpler for slip forms than jump forms. Loads tend to remain relatively constant during the slide, without the cycles of critical to non-critical loading experienced with jump forms.

The lateral hydrostatic pressure generated by the fresh concrete is resisted by the form sheathing, in turn supported by the wales, and then transferred to the legs of the yokes. The yokes retain the pressure through their portal frame action. Similarly, lateral loadings from wind and other forces are delivered to the concrete walls by the yoke.

The vertical loads of the scaffolds and work decks are also supported by the yokes, which are in turn supported by the climbing rods through their attachment to the hydraulic jacks. Therefore, all vertical loads, including those from attached elevators and hoists, are borne by the climbing rods acting as slender compression columns. Due to the unsupported height of the rods, their

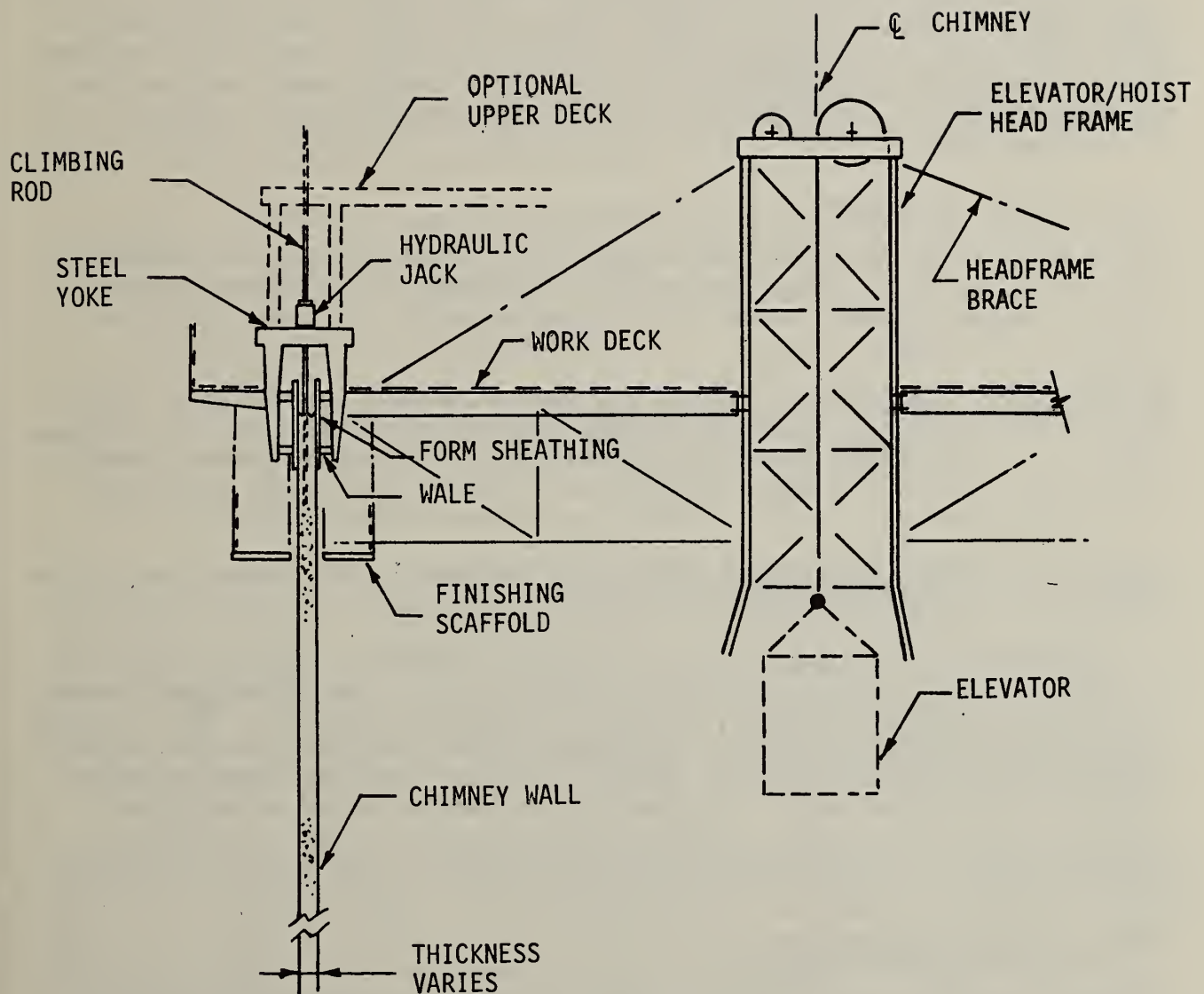


Figure 4.1 Self-climbing chimney slip form

design must consider buckling; auxiliary bracing is usually provided for systems using tall yokes. If such designs are in use, inspectors should be careful to ensure the use of required bracing.

Since there are no anchor bolts used in this system of slip forms, many precautions noted with other form systems are automatically eliminated.

Design, mixing, and placement of the concrete are critical items due to the continuous operations employed and the extremely low age of the exposed concrete as it emerges from the bottom of the forms. Inspection must be continuous to insure the uniformity of mix, setting time, and strength. Various in-place test methods are used to estimate the effective strength of the concrete in the forms and necessary adjustments are made to the slipping rate. Cold weather requires generally lower rates while hot weather usually means increased construction rates.

4.2.3 Access and Egress

Access from ground level to the working level of chimney slip forms becomes very restricted as the height increases. Near ground level, stair towers are used to provide personnel access, but elevators and/or personnel hoists are required at the higher levels.

The work decks and scaffolds provide horizontal access to all areas of the forms once personnel are delivered to the working level. As with other systems, ladders are used at intermittent locations for access between various levels. Unlike some jump form systems, there are no interruptions to the horizontal access during moving, since the entire system moves as a unit.

Inspection of the scaffolding system should involve the same precautions as for jump forms; review section 3.2.3 for general discussions.

Because of the extraordinary heights and limited access, emergency evacuation of personnel is also restricted. Therefore, design of the system must consider all potential load criteria in the event of accidental distress. The slip form elements are integrated into one unit, which could represent a potential chain reaction failure as discussed in section 3.3.2, but the differences in load transfer reduce such risks. The yokes are constantly in contact with both sides of the concrete walls, adding stability to the system. In addition, moments induced in the near-vertical walls are minimal and should not produce high stresses.

4.2.4 Critical Safety Items

Concrete strength is the primary concern for system safety; procedures for batching, placing, and curing must produce consistent quality and strength. Job records and field tests should satisfy inspectors that procedures and materials in use are producing specified strengths.

The stability of the climbing rods is important to the safe operation of the overall system. Long exposed sections must be adequately braced to provide the

necessary design stability. Such bracing applies not only to rod sections cantilevered above the concrete wall, but also sections which may be exposed in wall blockouts.

The hydraulic system for operation of the jacks should provide for synchronized jack movements to prevent overloads of individual units that could lead to localized overstressing.

Care must be taken to maintain proper form contact and lubrication with the concrete being placed. Dry mixes cause extra sliding friction and adherence to the forms, which can lead to horizontal cracks in the walls as the forms tend to lift the concrete. By the same action, additional loads are applied to the climbing rods. Too little contact time can expose plastic concrete at the base of the forms; Operators are required to work within the limits which will provide the necessary safe strength and allow a reasonable rate of progress.

Scaffolding and walkway components should be regularly inspected and properly maintained at all times, in accordance with regulations (section 1926.451 [16]) and other recommendations in this manual.

4.3 CLIMBING MAST AND SLIP FORM SYSTEM

Another slip form system used in the construction of smaller chimneys consists of a central mast from which the slip form is suspended. Climbing rods are not required with the system; anchor bolts are utilized as supports.

4.3.1 System Description

A suspended mast located in the center of the chimney tower serves as the main structural element of the system. Radiating outward from the mast is a spider frame which extends to the outer diameter of the chimney and from which the slip form yokes are suspended (figure 4.2). As with the self-climbing slip forms, the yokes resist the hydrostatic pressure, scaffold loadings, and lateral wind loads. Lateral resistance to wind loads on the climbing system is provided through cantilever action of the yokes projecting downward onto the hardened concrete at the base of the forms. The wind loads are transmitted to the yokes by the exterior horizontal form wales and by the interior work deck.

The mast is suspended from its base on inclined cables connected to anchor locations on the interior of the partially completed chimney. As the slip form operation progresses higher, the mast cables are intermittently attached to new anchor points, and the mast "climbs" to a higher position with the new cables. Additional cables (or stabilizers, figure 4.2), are used to provide lateral stability to the mast. The previous suspension cables are then leap-frogged ahead to a new position.

The forms are raised by pulling them upward with hydraulic jacks or manual devices attached to the spider frame, which moves in incremental stages with the mast. Synchronization of the devices is required to prevent overloading certain areas of the slip form or spider frame and its anchorages.

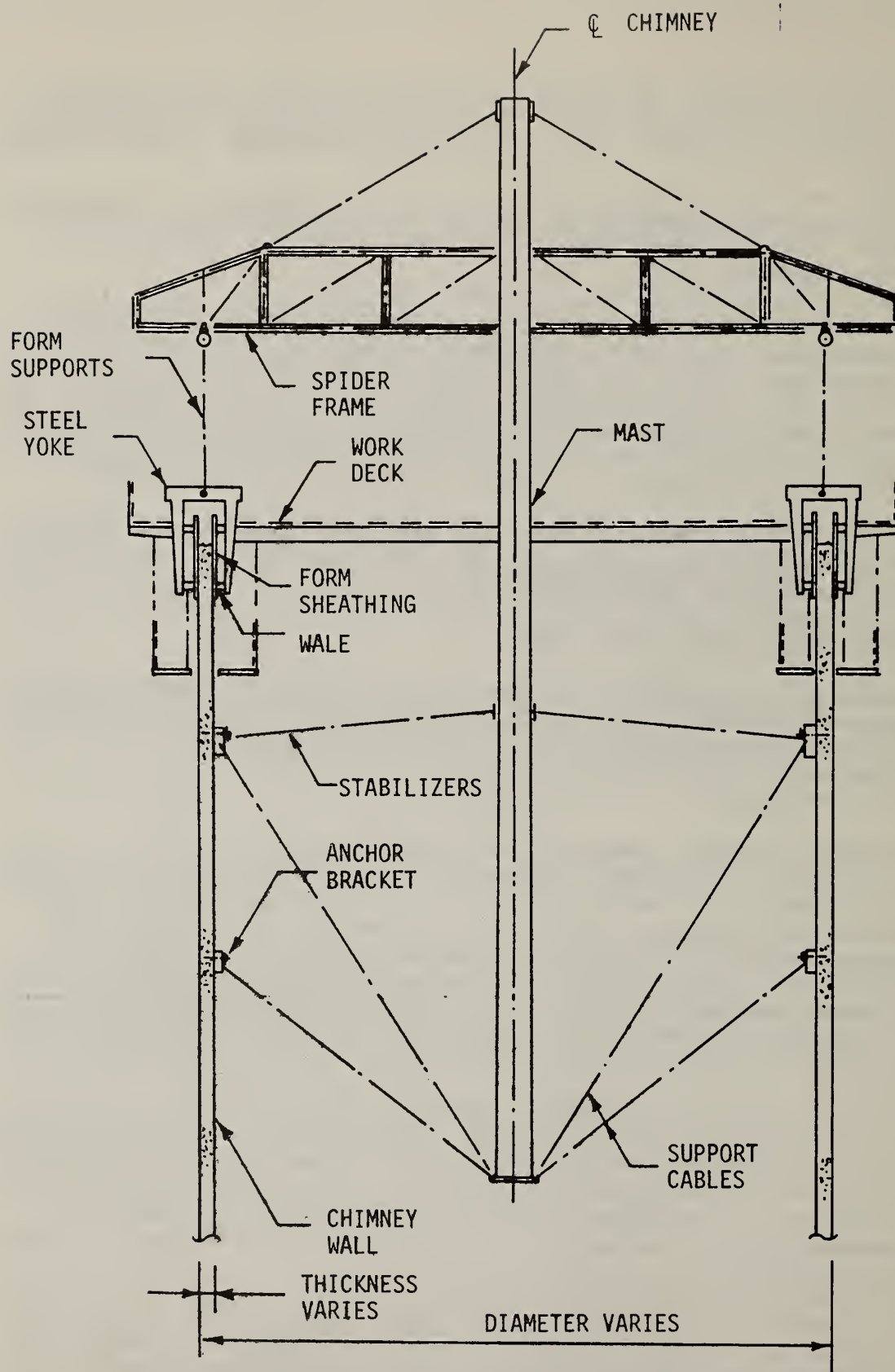


Figure 4.2 Climbing mast and slip form

4.3.2 Load Transfer

As with the self-climbing slip forms, the yokes in this system serve the function of supporting scaffolds, work decks, forms, hydrostatic pressures, and other lateral loads. All vertical loads including dead load, live loads, and sliding friction are carried by the spider frame and mast. The mast is in turn supported by the inclined cables, which are anchored into the chimney walls. Form systems on the shorter chimneys and other structures use masts which extend to foundations at ground level (figure 2.6 and ref. 14).

Since the mast is of primary importance, its support is critical to the overall system. Thus, the strength of the anchorage and the concrete become very critical items. A detailed analysis is required to determine loadings on each of the anchorages; special design and/or testing may be required to develop suitable anchorages for the partially cured concrete.

4.3.3 Access and Egress

As with other chimney constructions, access becomes very restricted once the chimney extends beyond normal crane reach from the ground. Personnel hoists on the interior provide the main access from ground level to the formwork deck. The deck extends over the whole interior of the chimney. A walkway at the same level provides access around the outside of the walls. Hanging scaffolds are used on the inside and outside to provide workmen access to the concrete below the forms. Inspection of these items should be in accordance with the guidelines discussed in section 3.2.3. Specific procedures for the installation, operation and maintenance of personnel hoists should comply with OSHA safety requirements (Section 1926.522(c), ref. 6, as amended in the Federal Register Volume 38, No. 63, April 3, 1973).

Without a means for rapid evacuation in the event of accidental distress, the design of this form system should have extra safety factors and considerations for potential overloading. The consequences of an anchor bolt failure are much more pronounced than with the self-climbing slip form system, although the yokes which straddle the chimney walls should prevent collapse of the whole system if an anchor failed. However, there would probably be structural damage and personal injury if the center mast lost its support at one or more locations. The materials and procedures used at the anchorage locations should be regularly checked to insure that design criteria are being satisfied. Personnel should be trained as to the significance of the various interrelated parts.

4.3.4 Critical Safety Items

The concrete and the anchorages are the most critical items in this system. Since they directly support the mast, which is the most critical structural element, their importance cannot be overemphasized. The concreting procedures must be satisfactory to consistently produce strength and quality which meet all design specifications. The anchorage components must be fabricated, installed, and used as intended by the system designer; missing or improperly placed anchorages are important inspection targets.

Since the mast is suspended on cables, inspection of the cables and their connections must be in accordance with existing regulations and normal safety precautions.

Accessways and work devices should be checked according to recommendations of these guidelines and pertinent regulations.

Section 3.2.4 should also be reviewed for items applicable to this system.

5. OTHER TYPES OF CONSTRUCTION

This document has discussed form and scaffold systems used in the construction of reinforced concrete natural draft cooling towers and chimneys, with emphasis on safety aspects. Many of the considerations pertaining to those structures are applicable to other types as well.

Jump form systems are used in the construction of commercial buildings, retaining walls, bridge piers, shafts, cooling towers, nuclear containment vessels and numerous other structures. Slip forms are routinely used on chimneys, silos, concrete towers, and other similar structures [13]. Where jobsite conditions permit, slip forms are also used to construct buildings, piers, shafts, and containment vessels.

Those structures most similar to cooling tower construction and chimney construction are discussed below.

5.1 SILOS

Slip forms are commonly used to construct storage silos. They are usually formed in monolithic clusters. The silos may be used for storage of grain, coal, cement, and similar bulk materials. With regard to construction procedures, they are not different from those for other types of structures. Heights are usually such that materials are delivered to the working level of the forms with mobile cranes; personnel elevators are commonly used for access.

The natural stability of the silo clusters adds to the safety of the construction process; the concrete remains as the critical structural safety item. Personal safety is threatened more by the extent and variety of accessways in the clusters of forms and by the crane-handled materials than by other factors. Inspectors should review training procedures for personnel and normal safety precautions for elevated work areas (also refer to chapter 4).

5.2 CONTAINMENT VESSELS

Nuclear containment vessels at power plants are normally constructed with jump forms due to the complexities, tolerances, and critical inspections for embedded materials. The jump form systems operate on a similar basis as those for cooling towers, but the construction of the raisers is somewhat different.

Since lifts are only made every 2 to 4 weeks, the raisers need not be designed for lifting speed. They are designed to handle considerably heavier loads, however, and use hydraulic cylinders to perform the lifting operations. Lifts are commonly made in 7.5 to 10 ft (2.3 to 3.0 m) increments to reduce the quantity of construction joints; therefore, larger and heavier-duty form sections are utilized. With the heavier loads being handled, anchor bolt loads are increased significantly from those of cooling towers. The anchorages and the concrete strength still remain as critical safety items, as with the cooling tower systems discussed in chapter 3.

6. SUMMARY AND CONCLUSIONS

6.1 GENERAL SAFETY PROVISIONS

There are numerous safety aspects to consider in construction; they are affected not only by the structural and environmental aspects of the form and scaffold system in use, but also by the strength and stability of the partially completed structure. As noted previously, the early age of the concrete is a critical item and can control the rate of progress. Similarly, the design, manufacture, and installation of anchorages in the young concrete are important items. Jump form systems rely heavily on strengths of previous lifts to resist construction loads and moments; vertical slip forms do not typically apply eccentric loads to lifts below but are dependent on the strength of concrete at very early ages.

Training of personnel is important to the safe operation of any construction system. It is a critical item in the use of jump form and slip form systems. The sequencing and execution of the many procedures involved can affect the overall safety of the system, including the partially completed structure. The contractor should implement safety inspection procedures which should be part of the field records. Personnel should be made aware of the interrelationships of the various system components and be cautioned as to the critical elements.

Accessways should be available for use at all times, without restrictions caused by debris or other items. Alternate routes must be made available in the event normal access is interrupted. Ladders between work levels should be secured and available at all times; access hatches should be clearly marked and available at any time.

6.2 CONSTRUCTION REVIEWS

Preconstruction reviews can be useful in acquainting jobsite personnel and other associated personnel with planned construction methods, form and scaffold systems, materials delivery systems, schedules, and overall operating procedures. Compliance officers can be informed of safety procedures to be in effect and notified of persons responsible for reporting.

Preliminary discussions should include basic construction procedures and schedules, as well as design loading criteria for the form and scaffold system. More specific procedures, schedules, and loads can be provided with design drawing submittals at a later time, but prior to starting construction. Critical conditions or loads should be clearly noted; key operations should be denoted and appropriate safety measures put into effect.

Regular or periodic construction meetings can be effectively used to review progress of construction and to discuss changes to operating procedures, equipment, and/or personnel.

Specific bench marks should be established for all key operations; these should include, but not necessarily be confined to, minimum concrete strength for form

removal, minimum concrete maturity, minimum size and number of anchor bolts, and their proper placement, sequence of operation, maximum deck loads, minimum size and number of scaffold connections, maximum concrete casting rates and size and spacing of form ties. Inspections should be adequate to assure the bench marks are being met. Job site records can be satisfactorily used to review many items. Some items will require detailed inspections to be performed.

6.3 CONCLUSIONS AND RECOMMENDATIONS

There are a number of key factors influencing the overall structural integrity of moving formworks used in the construction of cooling towers and chimneys. The principal forming systems, which have been addressed in this manual, can not be treated independently of the partially completed structure. The forms, scaffolds, moving mechanisms and the structure combine to form an interactive construction system in which the safety of individual components is affected by the design and operation of other components. A working knowledge of the operational aspects of the systems will ensure meaningful field evaluation of system safety by compliance officers.

Among critical safety items, the capacity of partially matured concrete to resist imposed construction loads with an adequate margin of safety should receive foremost priority. The minimum factor of safety should be maintained at a level consistent with the design of concrete structures for occupancy loads for two important reasons. First, service loads and fully developed concrete strength are more predictable than construction loads and the strength of concrete at early ages. Second, the consequences of a construction failure in terms of human casualties would be quite severe owing to the fact that moving form systems are generally well-populated and inherently limited in providing the exitways for emergency evacuation of personnel in the event of structural distress. In addition, where the partially cured concrete supports loads transmitted by scaffolds and other work platforms, its strength requirements should be consistent with the safety factors prescribed by the construction safety regulations of OSHA.

The compliance officer should expect to find field records which will show, above all else, that the construction system is well-conceived and structurally sound with regard to the maintenance of a minimum factor of safety on component strengths. The engineer's records should be sufficiently comprehensive to indicate, through a detailed set of specifications, critical benchmarks for the movement of forms and imposition of loads on partially cured concrete. The field logs should show these bench marks are being met. The proper implementation of these items is the key requirement contained in OSHA and ANSI regulations (OSHA 1926.701(a)(4) [16], or ANSI A10.9-6.3.4).

Many of the safety hazards found in cooling tower and chimney construction are universal in application. Accessways must be available at all times, without blockage by debris or other items. All structural connections of the scaffolding and forming systems must be sound and adequate for the intended loads. Any signs of distress in the system, such as cracking, peeling, bending, etc., should be noted and remedial measures taken immediately. Structural

engineering consultants may be needed in the evaluation of certain moving form systems which incorporate relatively complex mechanisms (such as catheads used in conjunction with flexible cables to transport concrete to the top of the tower) capable of producing extraordinary loads on the partially matured concrete structure.

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APPENDIX A

GLOSSARY

- ACCESSWAY -- route for personnel access and egress. May include scaffolds, ladders, stairs, elevators, and other similar items.
- ANCHORAGE -- the assemblage of components used in transferring loads into a supporting structure or foundation.
- ANCHOR BOLT -- removable external fastener used to transfer loads to embedded device of an anchorage.
- ANCHOR CLAMP -- device used with anchor bolt to apply clamping pressure on forms in order to reduce loss of grout at construction joints.
- CLIMBING FORM -- form which is raised vertically, with self-contained mechanical device, for succeeding lifts of concrete.
- CLIMBING RODS -- slender compression devices used with slip forms to support the vertical loads. Usually embedded in concrete being formed with vertical projection for attachment to hydraulic jacks used for raising the formwork.
- CONSTRUCTION JOINT -- surface where succeeding lifts of concrete meet.
- COMPONENT -- a member of an assemblage.
- FORMS -- term used interchangeable with "formwork" or "form system." More specifically, the supporting components of formwork which are in direct contact with concrete being molded.
- FORMWORK -- an assemblage of form panels, strongbacks, scaffolds, mechanical components, etc. for use in molding concrete.
- FORM PANEL -- component of formwork, usually rectangular, consisting of sheathing and backing members (stiffeners). Panel usually grouped into gangs to mold a specific portion of a structure.
- JACKING FRAME -- designation for raiser used in a specific jump form system.
- JUMP FORM -- climbing form moved vertically to succeeding lift positions after concrete has partially cured.
- JUMPFORM BEAMS -- designation for raiser used in a specific jump form system.
- RAISER -- mechanical device used to move jump forms vertically to succeeding lift positions. Usually serves multiple function as strong-back.
- RATCHET -- mechanical device used in raising loads through leverage action of a pawl bearing on lugs (or notches), with one or more other pawls interlocking on alternate lugs (or notches) to prevent reverse movement of the load.

SCAFFOLDING -- material used for scaffolds.

SCAFFOLDS -- elevated platform for workmen or materials.

SLIP FORM -- climbing form moved semi-continuously while concrete is being placed.

STIFFBACK -- term used interchangeably with "strongback."

STRONGBACK -- structural vertical component used to add stiffness to forms. Normally used to transfer unbalanced formwork loads to anchorage.

TIE -- tensile device connecting opposing form panels in order to resist lateral hydrostatic pressures.

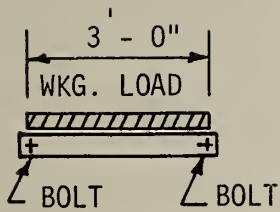
WALE -- structural component for holding form panels in prescribed positions.

WALKWAY -- term used interchangeably with "scaffolds." More specifically, a scaffold designed for personnel loading.

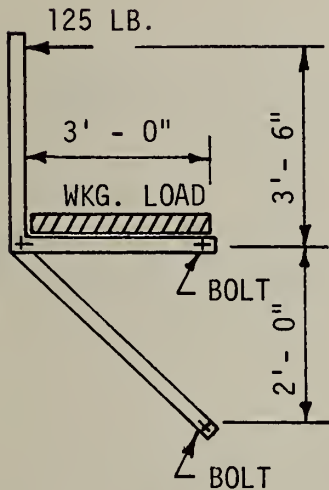
YOKE -- structural frame component of slip forms to absorb lateral concrete pressure and to transfer vertical loads to climbing rods.

APPENDIX B

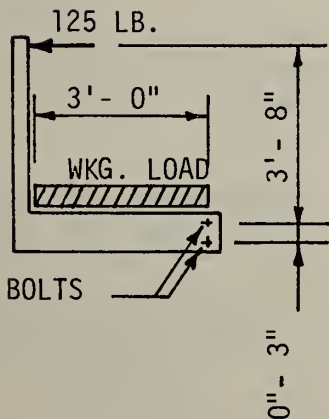
Minimum Scaffold Bolt Diameters



Simply Supported Bracket					
Spacing of Brackets	Area Supported (sq. ft.)	Min. Bolt Diam. (in) (A307)*			Est. Scaf. Weight
		25 PSF W.L.	50 PSF W.L.	75 PSF W.L.	
6 ft.	18	1/2φ	1/2φ	1/2φ	8 PSF
8 ft.	24	1/2φ	1/2φ	1/2φ	
10 ft.	30	1/2φ	1/2φ	1/2φ	
12 ft.	36	1/2φ	1/2φ	1/2φ	12 PSF
14 ft.	42	1/2φ	1/2φ	1/2φ	
16 ft.	48	1/2φ	1/2φ	5/8φ	



Braced Scaffold Bracket					
Spacing of Brackets	Area Supported (sq. ft.)	Min. Bolt Diam. (in) (A307)*			Est. Scaf. Weight
		25 PSF W.L.	50 PSF W.L.	75 PSF W.L.	
6 ft.	18	1/2φ	1/2φ	5/8φ	8 PSF
8 ft.	24	1/2φ	1/2φ	5/8φ	
10 ft.	30	1/2φ	1/2φ	5/8φ	
12 ft.	36	1/2φ	5/8φ	3/4φ	12 PSF
14 ft.	42	1/2φ	5/8φ	3/4φ	
16 ft.	48	1/2φ	5/8φ	3/4φ	



Cantilevered Scaffold Bracket					
Spacing of Brackets	Area Supported (sq. ft.)	Min. Bolt Diam. (in) (A307)*			Est. Scaf. Weight
		25 PSF W.L.	50 PSF W.L.	75 PSF W.L.	
3 ft.	9	3/4φ	7/8φ	1 φ	5 PSF
4 ft.	12	3/4φ	7/8φ	1 φ	
5 ft.	15	7/8φ	1 φ	1-1/8φ	
6 ft.	18	7/8φ	1-1/8φ	1-1/4φ	8 PSF
7 ft.	21	1 φ	1-1/8φ		
8 ft.	24	1 φ	1-1/4φ		

* All bolt sizes based on Single Shear loading; Min. size limited to 1/2 in.

APPENDIX C

WEIGHTS AND CONNECTOR CAPACITIES

Allowable Shear Loads on Bolts, lbs.

GRADE OF BOLT	NOMINAL DIAMETER, in						
	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4
A 307	1,900	3,100	4,400	6,000	7,900	9,900	12,300
A 325	N/A	5,400	7,700	10,500	13,700	17,400	21,500

Allowable Shear Loads on Pins, lbs.

GRADE OF PIN	NOMINAL DIAMETER, in						
	1/2	5/8	3/4	7/8	1	1-1/8	1-1/4
A 36	2,800	4,400	6,300	8,600	11,300	14,300	17,700
C1018-CR	5,500	8,600	12,400	16,800	22,000	27,800	34,400

Weights of Form and Scaffold Systems *

ITEM	ITEM WEIGHT
Form Panels	
All steel, 3/16" skin plate	15 psf
Steel frame, 3/4" plywood face	10 psf
Wood frame, 3/4" plywood face	5 psf
Joists	
Double 6" steel channel	18 psf
Double 2x8" wood	8 psf
Scaffold Planking	
2x12 SAS (finished)	6 psf
2x12 rough sawn	8 psf
3x12 rough sawn	12 psf

ITEM	ITEM WEIGHT
Strongbacks	
Double 8" steel channel	25 PSF
Trussed	See Mfgr.
Telescopic	See Mfgr.

* Weights shown are general weights for use in approximating dead loads. Specific weights should be used where available.

APPENDIX D

CHECK LIST FOR
INSPECTION OF JUMP FORM SYSTEM

<u>REFERENCE DOCUMENTS</u>	<u>REVIEWED</u>
Tower drawings	_____
Formwork drawings	_____
Formwork calculations	_____
Sequence of moving cycle	_____
Criteria for form movement	_____
Concrete records	_____
Material test records	_____
Maintenance records	_____

<u>GENERAL</u>	<u>YES</u>	<u>NO</u>
Overall formwork condition adequate	_____	_____
Routine maintenance performed	_____	_____
Regular inspections performed:	_____	_____
Concrete	_____	_____
Anchorages	_____	_____
Accessways	_____	_____
Forms	_____	_____
Training provided for personnel	_____	_____
Form movement criteria observed	_____	_____
Signs of overload or structural distress	_____ *	_____

* If answer is yes, explain further. _____

CONCRETEDESIGNOBSERVED

28-day compressive strength, psi

Max. slump, in.

Max. water/cement ratio

Min. compr. str. for form movement

Min. comp. str. for placing concrete in
succeeding lift

General Comments: _____

ANCHORAGESDESIGNOBSERVEDDesign working load (in _____ psi concrete,
with _____ safety factor)

Shear, lbs. _____

Tension, lbs. _____

Nominal size of embedment

Nominal size of anchor bolt

Min. anch. bolts per strongback

General Comments: _____

ACCESS/EGRESS

Level 1 (top) scaffold (_____ simple; _____ braced; _____ cantilevered)

DESIGNOBSERVED

Live load, psf

Spacing of scaffold brackets

Nom. bolt sizes

Level 2 Scaffold (____simple, ____braced, ____cantilevered)

	<u>DESIGN</u>	<u>OBSERVED</u>
Live load, psf	_____	_____
Spacing of scaffold brackets	_____	_____
Nom. bolt sizes	_____	_____

Level 3 Scaffold (____simple, ____braced, ____cantilevered)

	<u>DESIGN</u>	<u>OBSERVED</u>
Live load, psf	_____	_____
Spacing of scaffold brackets	_____	_____
Nom. bolt sizes	_____	_____

Level 4 Scaffold (____simple, ____braced, ____cantilevered)

	<u>DESIGN</u>	<u>OBSERVED</u>
Live load, psf	_____	_____
Spacing of scaffold brackets	_____	_____
Nom. bolt sizes	_____	_____

Miscellaneous Comments:

Ladders: _____

Stairs: _____

Elevators: _____

Guardrails: _____

Toe boards: _____

Maintenance: _____

General Comments: _____

HOISTING SYSTEMDESIGNOBSERVED

Main hoist line

Min. sheave size

Min. line size

Static line

Min. sheave size

Min. line size

Max. tension

Max. hoist load

General Comments: _____

RAISERSYESNO

Mechanical components checked regularly

Safety mechanism operating properly

Regular maintenance performed

General Comments: _____

APPENDIX E

CHECK LIST FOR

INSPECTION OF SLIP FORM SYSTEM

REFERENCE DOCUMENTS

REVIEWED

Chimney drawings

Formwork drawings

Formwork calculations

Criteria for slipping rate

Concrete records

Material test records

Maintenance records

GENERAL

YES

NO

Overall formwork condition adequate

Routine maintenance performed

Regular inspections performed

Concrete

Climbing rods

Anchorage

Accessways

Forms

Training provided for personnel

Form slipping criteria observed

Signs of overload or structural distress

_____ *

*If answer is yes, explain further _____

CONCRETEDESIGNOBSERVED

28-day compressive strength, psi

Max. slump, in.

Max. water/cement ratio

CLIMBING RODSDESIGNOBSERVED

Diameter of rods, in.

Unbraced length, in.

Dist between climbing rods, ft.

General Comments: _____

ANCHORAGE (climbing mast system)DESIGNOBSERVEDDesign working load (in _____ psi concrete,
with _____ safety factor)

Shear, lbs. _____

Tension, lbs. _____

Nominal size of embedment

Nominal size of anchor bolt

General Comments: _____

ACCESS/EGRESSDESIGNOBSERVEDMain work deck
Live load, psf

Level 1 (TOP) scaffold (____simple; ____braced; ____cantilevered)

DESIGN OBSERVED

Live load, psf

Spacing of scaffold brackets

Nom. bolt sizes

Level 2 scaffold (____simple; ____braced; ____cantilevered)

DESIGN OBSERVED

Live load, psf

Spacing of scaffolds brackets

Nom. bolt sizes

Level 3 scaffold (____simple; ____braced, ____cantilevered)

DESIGN OBSERVED

Live load, psf

Spacing of scaffold brackets

Nom. bolt sizes

Miscellaneous Comments:

Ladders: _____

Stairs: _____

Elevators: _____

Guardrails: _____

Toe boards: _____

Maintenance: _____

General Comments: _____

YOKES/HYDRAULIC JACKS

YES

NO

Level controls adequate

—

—

Safety mechanisms operating properly

—

—

Regular maintenance performed

—

—

General Comments:

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 82-2627	2. Performing Organ. Report No.	3. Publication Date March 1983
4. TITLE AND SUBTITLE A GUIDE FOR SAFETY INSPECTION OF JUMPFORM AND SLIPFORM SYSTEMS USED IN CONCRETE COOLING TOWER AND CHIMNEY CONSTRUCTION			
5. AUTHOR(S) S. G. Fattal			
6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions) NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			7. Contract/Grant No. 8. Type of Report & Period Covered
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP) Occupational Safety and Health Administration Department of Labor Washington, D.C.			
10. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.			
11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here) The increasing use of moving forms in the construction of many types of structures has prompted the need for special quality control measures in the field. Presently, slip forming and jump forming are the most widely utilized systems in the construction of cooling towers, chimneys, silos and nuclear reactor containment vessels. This report provides a basic guide for the safety inspection of jump form and slip form systems used in the construction of cooling towers and chimneys. The systems are described in terms of their components and operating procedures involved in the casting cycle of a typical lift. Special emphasis is given to the structural aspects of components which are most critical in the maintenance of overall structural integrity of the system during construction.			
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons) chimneys; concrete strength; construction loads; construction safety; construction standards; cooling towers; jump forming; slip forming; structural safety			
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